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PREFACE

This publication is a compilation of summaries of reports written by Principal Investigators funded through the Planetary Astronomy Program of NASA's Solar System Exploration Division, Office of Space Science and Applications.

The summaries are designed to provide information about current scientific research projects conducted in the Planetary Astronomy Program and to facilitate communication and coordination among concerned scientists and interested persons in universities, government, and industry.

The reports are published as they were submitted by the Principal Investigators and have not been edited. They are arranged in alphabetical order.

In a second section, highlights of recent accomplishments in planetary astronomy are summarized as they were submitted by the Principal Investigators. The name attached to an individual paragraph is generally the name of the person who submitted that paragraph.

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Solar System Exploration Division

May 1990

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Harrington, R.S.	USNO	Search for Planet X
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Knacke, R.F.	MSC	Infrared Spectroscopy of Jupiter and Saturn
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Larson, S.M.	UAZ	Cometary Spectroscopy and Imaging

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Lutz, B.L.	LWEL	Outer Planet Studies
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Matson, D.L.	JPL	Asteroid Research
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Potter, A.E.	JSC	Atmospheres of Mercury and the Moon
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Tedesco, E.F.	JPL	Asteroid Shapes and Pole Orientations from Visual and Infrared Photometry
Telesco, C.M.	MSC	Infrared Imaging of Comets
Terrile, R.J.	JPL	Planetary Optical and Infrared Imaging
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Tholen, D.J.	UHI	Visible and Infrared Investigations of Planet-Crossing Asteroids and Outer Solar System Objects
Trauger, J.T.	JPL	Planetary Fabry-Perot Spectroscopy
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Yeomans, D.K.	JPL	Comet and Asteroid Dynamics

HIGHLIGHTS OF RECENT ACCOMPLISHMENTS

Observations of Comets and Asteroids

Astronomy Program
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College Park, Maryland

Michael F. A'Hearn

a. **Strategy:** We use all available ground-based observational techniques to study the chemical and physical properties of the small bodies of the solar system, primarily comets and secondarily asteroids. The ultimate goal is to use these bodies to understand the formation and evolution of the solar system.

b. **Accomplishments:**

i) Completed reduction and archiving of IHW photometric data. Reduced and archived ~18,000 observations from count rate to fluxes. Archived an additional ~3,000 broad-band magnitudes.

ii) Collaborated with R.H. Brown to model our photometric data on cometary nuclei with his 3-dimensional ellipsoid fitting model. To fit the data, the nuclei must have significant differences between the intermediate and short axes (like P/Halley) and have significant variation in albedo.

iii) Initiated an analysis of the expansion velocity of the material in the gaseous jets we discovered in P/Halley's coma.

iv) Upgraded ccd system to have automatic control of filter and aperture mechanisms. A laboratory blunder led to a major failure of the control computer while attempting to test system observing comet O-L-R. System then repaired and rebuilt but virtually no new data this year.

v) Re-reduction of 14-year data set of photometry continues at Lowell Observatory with low-level involvement of PI.

c. **Plan:** i) Observations of comet Austin with BIMA (Hat Creek millimeter array) to map HCN and with ccd system to map CN and other species. ii) Ground-based observations of Ceres to follow up results from IUE relevant to previous observations of ice by Lebofsky. iii) Ground-based observations of Hidalgo to search for cometary activity. iv) Observations of P/Encke and P/H-M-P with ccd system.

d. **Publications:**

Hoban, S., A'Hearn, M.F., Birch, P.V., and Martin, R. 1989, *Spatial Structure in the Color of the Dust Coma of Comet P/Halley*, ***Icarus***, **79**, 145-158.

Weissman, P.R., A'Hearn, M.F., McFadden, L.A., and Rickman, H. 1989, *Evolution of Comets into Asteroids* in ***Asteroids***, ed. Binzel and Matthews, U. Arizona Press (in press).

A'Hearn, M.F., Campins H., Schleicher, D.G., Millis, R.L. 1989, *The Nucleus of Comet P/Tempel 2*, ***Ap.J.***, **347**, 1155-1166.

Osborn, W.H., A'Hearn, M.F., Carsenty, U., Millis, R.L., Schleicher, D.G., Birch, P.V., Moreno, H. and Guiterrez-Moreno, A. 1990, *Standard Stars for Photometry of Comets*, ***Icarus*** (submitted).

Theoretical Spectroscopy of Comets

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Michael F. A'Hearn

a. **Strategy:** We calculate theoretical spectra of various emitting species in cometary comae both to investigate physical parameters that are measureable with cometary spectra and to provide fluorescence efficiencies for the derivation of abundances from fluxes.

b. **Accomplishments:**

i) Calculated spectrum of atomic carbon to investigate feasibility of measuring total carbon abundance in comets using Antarctic sub-man Telescope. Model not yet complete enough to be sure.

ii) Re-analyzed SO abundances to investigate possible errors in previous analysis.

iii) Revised paper on time-dependent model for S_2 to accommodate referees.

iv) Continued analysis of CS in IUE spectra showing that although model involving tracking errors does not fit complete profile, the deviations are probably noise.

v) Completed zeroth-order model for SO_2 spectrum.

c. **Plan:** i) As last year, publish the half-finished manuscripts. ii) Complete the model of SO_2 including additional effects. iii) Extend to other carbon compounds.

d. **Publications:** 1989-90

Kim, S.J. and A'Hearn, M.F. 1989, *Sulfur Compounds in Comets,* CNRS workshop proceedings (in press)

Kim, S.-J. and A'Hearn, M.F. 1990, *Multi-cycle Fluorescence: Application to S_2 in Comet IRAS-Araki-Alcock (1983d).* ***Icarus*** (in press).

Planetary Research at the Lowell Observatory

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a. Strategy. In this grant we seek to understand the physical properties of comets by applying a wide variety of observational techniques. We particularly emphasize simultaneous or coordinated observations in different spectral regions (e.g., visible and thermal IR or visible and far UV) or with different instrumentation (imaging, spectroscopy, photometry). We aim to (1) measure the basic properties of cometary nuclei by studying comets whose comae are so anemic that the signal from the nucleus can be extracted, (2) investigate the group characteristics of comets by narrowband photometry applied uniformly to a large sample of comets, (3) understand the detailed physics and chemistry occurring in cometary comae through wide-field CCD imaging using narrow filters and through long-slit CCD spectroscopy, and (4) investigate the response of individual comets to changing insolation by means of extended narrowband photometry.

b. Accomplishments. In the past year we have completed a lengthy investigation of periodic variations in the activity of Comet P/Halley. Data from four observatories (Lowell, CTIO, MKO, and Perth) spanning 164 observing nights in 1985 and 1986 were included. Clear evidence of a period near 7.4 days was found in much of the data. We show that certain dynamical models of Halley's nucleus, advanced to account for claimed multipliperiodic behavior, are excluded by our observations. This work has been submitted for publication. An extensive set of coordinated observations of Comet P/Brorsen–Metcalf were acquired in August 1989 using a conventional photometer on the Lowell 42-inch telescope, a long-slit CCD spectrograph on the Perkins 72-inch telescope, and a Texas Instruments 800x800 CCD on a Takahashi ε-200 f/4 telescope. Narrowband observations of 5 comets were obtained during the year, bringing to 77 the total number of comets included in our database. The probability of detecting planetary systems around other stars, astrometrically or spectroscopically, was analyzed theoretically in terms of three different models for planetary-system scaling parameters.

c. Expected Accomplishments. In the next year, we will reduce and publish our large body of photometric observations of Comet Halley using the best currently available molecular parameters. Our extensive database of comet photometry mentioned above will be similarly re-reduced and published. An extensive series of observations of Comet Austin is currently underway and will be accelerated in April and May, when the comet is well placed for observation from the northern hemisphere. Wide-field CCD imaging, long-slit spectroscopy, and narrowband photometry will all be applied to this comet, as was done last year for Comet P/Brorsen-Metcalf. Analysis of existing CCD images of a number of comets aimed at understanding the evolution of grains moving through the coma is nearing completion and will be published. Finally, observations of newly discovered comets will be undertaken as circumstances warrant.

Summary Bibliography

A'Hearn, M. F., Campins, H., Schleicher, D. G., and Millis, R. L. (1989). "The Nucleus of Comet P/Tempel 2," *Astrophys. J.* **347**, 1155–1166.

Osborn, W., A'Hearn, M. F., Carsenty, U., Millis, R. L., Schleicher, D. G., Birch, P. V., Moreno, H., Gutierrez-Moreno, A., and Wenderoth, E. (1990). "Standard Stars for Comet Photometry." *Icarus*, submitted.

Schleicher, D. G., and Millis, R. L. (1989). "Revised Scalelengths for Cometary NH." *Astrophys. J.* **339**, 1107–1114.

Schleicher, D. G., Millis, R. L., Thompson, D. T., Birch, P. V., Martin, R.,Tholen, D. J., Piscitelli, J. R., Lark, N. L., and Hammel, H. B., (1990). "Periodic Variations in the Activity of Comet P/Halley During the 1985/1986 Apparition." *Astronomical Journal*, submitted.

Schleicher, D. G., Osip, D. J., and Millis, R. L. (1989). "Production Rates of Comet P/Brorsen-Metcalf." *IAU Circular* No. 4810.

Schleicher, D. G., Osip, D. J., and Birch, P. V. (1990). "Production Rates of Comet Austin (1989c1)." *IAU Circular* No. 4983.

Long-Term Changes in the Reflectivity and Large-Scale Motions In the Atmospheres of Jupiter and Saturn

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Reta F. Beebe

a. A systematic data set of multicolor photometrically calibrated images of Jupiter and Saturn using a 0.6 meter telescope and a CCD camera is being being acquired. Broad-band filters at 440, 560, 660 and 755 nm. and narrow-band methane filters (889, 727, and 618 nm) provide information on changes in the vertical structure of the atmosphere. The data is acquired on a IBM-AT system along with standard stars and flat fields and is reduced at the telescope. Constrained deconvolution and navigation and reduction to the local frame-of-reference is carried out on a Compac-386 system. This cost-effective approach to the analysis of the data allows efficient monitoring of temporal variations in the atmospheres of Jupiter and Saturn.

b. We have acquired calibrated data sets for the 1989-1990 and 1990-1991 apparitions and are interpreting temporal changes in the Jovian cloud deck. The South Equatorial Belt (6-17^{0}S latitude) has brightened and the Equatorial Zone (7^0 N to 6^{0}S) has darkened. Data reduction is complete and modeling has begun to interpret these adjacent regions. At the same time, we have developed a system for encoding photographic images with a solid-state copy camera. Data spanning the entire 25 year database has been encoded and is being analyzed by Tom Little Nasa Graduate Student Research Fellow and Michael Flasar, GSFC. Cyclic changes in surface brightness of the North Temperate Belt (23 to 30^{0}N) with a period of 4.89 yrs. has been detected. Little plans to complete his research in late summer.

c. Graduate Student, David Kuehn, will continue analysis of the multicolor Jovian data and acquire an additional data set during the next apparition. The absolute calibration of this data set, coupled with the height sensitivity available in the methane filters, should provide a data set that will quantify cloud forming processes. Kuehn expects to complete his work in January of 1991. Undergraduate NASA Trainee, Lisa Brown, has completed her preliminary training in image processing and has begun image selection and encoding of the historical data. Our goal is to produce a pair of broad-band red and blue cylindrical maps of the morphology of the Jovian deck each apparition for a period of more than two Jovian years. This will provide a "quick-look" data base for comparing Voyager and Galileo observations.

d. Summary bibliography. Papers Presented in 1989-90 Based on the Data Set

Kuehn, D. M. and R. F. Beebe, A Deceleration of the White Ovals, Bulletin of the Amer. Astron. Soc. Vol 21, 1989, 945.

Little, T. A Time Series of Jovian Albedo Variation, Bulletin of the Amer. Astron. Soc. Vol 21, 1989, 945.

Beebe, R.F., D.M. Kuehn, and A.S. Murrell, Recent Variations in the Reflectivity of Jupiter's South Equatorial Belt, Bulletin of the Amer. Astron. Soc. Vol 21, 1989, 946.

Infrared Spectral Studies of Asteroids

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Jeffrey F. Bell

a) *Strategy:* The research objective is to improve our understanding of the surface mineralogy of asteroids and to link the vast existing body of meteorite geochemical data with specific astronomical objects which may be the targets of future NASA missions. The methodology employed is 1) use advanced astronomical instrumentation to obtain reflection spectra in the 0.3-5.2μm wavelength range of selected asteroids; 2) compare the asteroid data with similar data on simulated asteroid regoliths of various conpositions to determine the surface mineralogy and meteoritic affinities of asteroid spectral classes and specific asteroids; 3) intergrate the mineralogical information with other astronomical data, orbital dynamics studies, and meterorite geochemistry data to reconstruct the condensational, thermal, and collisional history of the present asteroids and their parent planetesimals; 4) use the information obtained to asist planning of future NASA asteroid missions such as Galileo and CRAF.

b) *Progress (2/89-2/90):* Completed reduction of 52-Color Asteroid Survey and distributed spectra to interested investigators; continued to observe selected members of the Eos family and other suspected K-class asteroids; provided information for selection of candidate asteroid flyby targets for Galileo and CRAF missions.

c) *Proposed Research (1990):* Continue to aquire 52-color spectra of selected S-type asteroids, Earth-crossers, members of asteroid dynamical families, and suspected K-types; continue to assist planning for Galileo and CRAF mission asteroid flybys; select filter system and begin observations for moderate resolution IR asteroid survey.

d) *Summary Bibliography (1989):* 4 papers published.

PUBLICATIONS (NAGW-802):

Bell, J. F., D. Davis, W. K. Hartmann, and M. J. Gaffey, Asteroids: The Big Picture. In ASTEROIDS II, (University of Arizona Press, 1989), pp. 921-945.

Gaffey, M. J., J. F. Bell, and D. P. Cruikshank, Reflectance Spectroscopy and Asteroid Surface Mineralogy. In ASTEROIDS II, (University of Arizona Press, 1989), pp. 98-127.

Chapman, C. R., P. Paolicchi, V. Zappala, R. P. Binzel, and J. F. Bell, Asteroid Families: Physical Properties and Evolution. In ASTEROIDS II, (University of Arizona Press, 1989), pp. 386-415.

Bell, J. F., Mineralogical Clues to the Origins of Asteroid Dynamical Families. *Icarus* **78**, 426-440 (1989).

Analysis and Interpretation of CCD Data on P/Halley

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Tucson, Arizona 85726

Michael J.S. Belton

(a) Objectives and Strategy

The scientific objectives of this investigation are: (1) to obtain an accurate, well sampled, photometric time-series of comet Halley which tracks the pre/post-perihelion asymmetry in the light curve, covers the final decay of the coma, and which covers a substantial portion of the light curve at a time when the cometary light is dominated by the reflection of sunlight from the nucleus itself; (2) to derive a precise ephemeris for the nuclear spin; (3) to separate the effects of rotation in the light curve from the effects of changes in the average rate of sublimation; (4) determine astrometric positions for the comet.

(b) Progress and Accomplishments to Date

The observing portion of this investigation has now been completed. The final observations were taken in the past year with the KPNO 4-m telescope, when the comet was at 10.7 AU from the sun. All the data have now been reduced to a calibratable form. All of the useful images have been flatfielded and submitted to the International Halley Watch (IHW) near-nucleus net for archiving. All of the data have been astrometrically reduced and 390 positions of the comet were submitted to the IHW astrometry net. The final photometric reductions are not yet complete; however R magnitudes and surface brightness gradients have already been derived for 48 images and included by the IHW photometry net. During our April, 1989 observing run to obtain observations of Halley for this project K. Meech and the PI discovered the first visible signs of an extended coma around Chiron, proving that it is a cometary object. This material has also been reduced and analyzed under partial support from this contract. A paper on the subject has been submitted to Astronomical Journal.

Future Work

The data is being analyzed in conjuction with data published by others, including the Vega and Giotto imaging data, in order to determine a precise description of the rotational state and degree of activity on the nucleus. In the past year we have already made great progresstowards this end by reducing the number of possible rotational states to three.

Publications:

Belton, M.J.S. 1990, "Rationalization of Comet Halley's Periods," Icarus, in press.

Belton, M.J.S. 1990, "Characterization of the Rotation of Cometary Nuclei," in Comets in the post-Halley Era, edited by R. Newburn and J. Rahe, in press.

Planetary Spectroscopy

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Jay T. Bergstralh

a. The goal of this task is to acquire physical data on the atmospheres of the outer planets and Titan by means of ground-based spectroscopy, spectrophotometry, and spectral imaging at visible to near-infrared wavelengths (approximately 0.3 to 2.5 microns). These data constrain physical parameters which characterize physical properties and distributions of aerosols in the atmospheres of these bodies. Work in the coming year will focus primarily on Neptune, to support the Voyager 2 encounter with that planet. This task includes only data acquisition and reduction; analyses are supported under separate funding.

b. Reduced spectral imaging of Neptune. The data were analyzed in several ways. Direct inspection of images reveals the distribution of discrete clouds in the atmosphere, which indicate that the global distribution of clouds has changed since earlier imaging: features now appear at higher (southern) latitudes. The rotation period derived from the later data is different from earlier values, suggesting a pattern of latitude-dependent zonal circulation such as we have seen on the other giant planets. Center-to-limb brightness profiles derived from the images will provide an additional constraint on location, albedos, and optical depths of aerosols in the troposphere and lower stratosphere.

c. (1) Three observing runs at Mauna Kea Observatory 2.24-meter telescope, to obtain CCD imaging at well-defined spectral bandpasses. Combined with earlier observations, these data will provide a continuous series of photometrically calibrated data over a timescale of several years. (2) Continued reduction of older data is also planned. (3) Report results at DPS meeting in Providence, Rhode Island.

d. Two oral presentations/abstracts (DPS); one paper in preparation.

Photometry of Pluto-Charon Mutual Events And Hirayama Family Asteroids

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Richard P. Binzel

(a) Once every 124 years, nature provides earth-bound astronomers with the opportunity to observe occultation and transit phenomena between Pluto and its satellite, Charon. Ground-based observations of these events will allow precise physical parameters for the Pluto-Charon system to be derived which are unlikely to be improved upon until *in situ* spacecraft observations are obtained. This program supports photometry observations from McDonald Observatory, a critical location in an International Pluto Campaign network. Knowledge of the diameters, masses, densities, and compositions derived from these observations will augment our understanding of Pluto's origin and its context within the problem of solar system formation.

A second task researches the evolutionary processes which have occurred in the asteroid belt by measuring the physical properties of specific Hirayama family members. Photoelectric lightcurve observations of Koronis and Themis family members will be used to investigate the individual catastrophic collision events which formed each family. By comparing these properties with results of laboratory and numerical experiments, the outcomes of catastrophic disruptions and collisional evolution may be more precisely determined.

(b) During 1989, observations were obtained for 9 mutual events. Reduction and analysis of 1985-1989 photometry has provided evidence for a bright south polar cap on Pluto and a possible color difference between the poles and the equator. A detailed mapping analysis is in progress.

New lightcurve observations have been obtained for 9 asteroids in the Koronis and Themis families where the Koronis observations have been performed at critical longitudes for estimating their pole orientations. A preliminary analysis suggests some preferential spin vector alignment.

(c) This year, four to six Pluto-Charon mutual events will be observed using the McDonald Observatory 2.1- and 2.7-m telescopes. Events in 1990--the final year of the mutual event season--will be partial transits and occultations involving the southern hemisphere of Pluto and the northern hemisphere of Charon. The McDonald data will be combined with those at other longitudes to allow the best possible solution to be derived for diameters, masses, and densities. These new observations will be combined with existing data to construct an albedo surface map for one hemisphere of each body.

Observations of ~10 Hirayama family asteroids will be obtained this year utilizing about 15 nights of 1-m telescope time at McDonald, Kitt Peak, and other observatories. Lightcurve observations of Koronis family asteroids at well-spaced ecliptic longitudes will be used to estimate their pole positions and to test whether their spin vectors have a preferential alignment, which is evidence for a recent formation. Observations of Themis family asteroids will broaden our understanding of catastrophic disruption events.

(d) Binzel, R. P. (1989). Pluto-Charon Mutual Events. *Geophys. Res. Lett.* **16**, 1205-1208, 1989.

Binzel, R.P. (1990). An Investigation of Spin Vector Alignment in the Koronis Family. In *Asteroids, Comets, Meteors III,* (C.-I. Lagerkvist, P. Magnusson, H. Rickman, eds.). pp.15-17.

Binzel, R.P., P. Farinella, V. Zappalá, and A. Cellino (1989). Asteroid Rotation Rates: Distributions and Statistics. In *Asteroids II,* (R. P. Binzel, T. Gehrels, M. S. Matthews, eds.). University of Arizona Press, Tucson. pp. 416-441, 1989.

Chapman, C., V. Zappalá, P. Paolicchi, R.P. Binzel, and J.F. Bell (1989). Asteroid Families: Physical Properties and Evolution. In *Asteroids II,* (R. P. Binzel, T. Gehrels, M. S. Matthews, eds.). University of Arizona Press, Tucson. pp. 386-415, 1989.

Binzel, R.P. (1988). "Hemispherical Color Distributions on Pluto and Charon" *Science* **241**, 1070-1072.

Binzel, R. P. (1988). "Collisional Evolution in the Eos and Koronis Asteroid Families: Observational and Numerical Results." *Icarus* **73**, 303-313.

Binzel, R. P., Tholen, D. J., Tedesco, E. F., Buratti, B., and Nelson, R. (1985). "The Detection of Eclipses in the Pluto-Charon System." *Science* **237**, 512-514.

Binzel, R. P. (1989). Pluto-Charon Mutual Events. *Geophys. Res. Lett.* **16**, 1205-1208, 1989.

Binzel, R. P. (1989). An Overview of the Asteroids. In *Asteroids II,* (R. P. Binzel, T. Gehrels, M. S. Matthews, eds.). University of Arizona Press, Tucson. pp. 3-19, 1989.

Binzel, R.P., P. Farinella, V. Zappalá, and A. Cellino (1989). Asteroid Rotation Rates: Distributions and Statistics. In *Asteroids II,* (R. P. Binzel, T. Gehrels, M. S. Matthews, eds.). University of Arizona Press, Tucson. pp. 416-441, 1989.

Binzel, R.P. (1990). An Investigation of Spin Vector Alignment in the Koronis Family. In *Asteroids, Comets, Meteors III,* (C.-I. Lagerkvist, P. Magnusson, H. Rickman, eds.). pp.15-17.

Chapman, C., V. Zappalá, P. Paolicchi, R.P. Binzel, and J.F. Bell (1989). Asteroid Families: Physical Properties and Evolution. In *Asteroids II,* (R. P. Binzel, T. Gehrels, M. S. Matthews, eds.). University of Arizona Press, Tucson. pp. 386-415, 1989.

Davis, D. , P. Farinella, P. Paolicchi, S. Weidenschilling, and R.P. Binzel (1989). Asteroid Collisional Evolution. In *Asteroids II,* (R. P. Binzel, T. Gehrels, M. S. Matthews, eds.). University of Arizona Press, Tucson. pp. 805-826, 1989.

French, L.M and Binzel, R.P. (1989). CCD Photometry of Asteroids. In *Asteroids II,* (R. P. Binzel, T. Gehrels, M. S. Matthews, eds.). University of Arizona Press, Tucson. pp. 54-65, 1989.

Studies of Asteroids, Comets, and Jupiter's Outer Satellites

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(a) Our work comprises observational, theoretical, and computational research, mainly on asteroids. Two principal areas of research, centering on astrometry and photometry, are interrelated in their aim to study the overall structure of the asteroid belt and the physical and orbital properties of individual asteroids.

(b) We have made excellent progress on LUKAS (Lowell Observatory–U.K. Schmidt Telescope Asteroid Survey), a deep (limiting B ~ 22.5 mag), bias-correctable survey, the aim of which is to determine the true spatial distribution of asteroids down to subkilometer diameters. Asteroid images on Schmidt plates have been identified by automatic scanning techniques (Russell *et al.* 1990). The irksome problem of fragmentation of stellar diffraction spikes mimicking faint asteroids is now quite well understood. We have worked on two fields centered on the L5 Trojan cloud and have identified about 50 new Trojans. We have also investigated what orbital information can be recovered from asteroid motion vectors (Bowell *et al.* 1990). Our astrometric collaboration with E. M. and C. S. Shoemaker, using their films from the 46-cm Palomar Schmidt has proceeded slowly, due to lack of manpower. An aim of this work—the U.S.G.S.–Lowell Asteroid Survey (GLAS)—is to discover and follow up moderately bright asteroids. GLAS thus complements LUKAS. CCD astrometry of very faint asteroids has been confined to a few selected targets. A review entitled "Discovery and Follow-up of Asteroids" (Bowell *et al.* 1989a) has been published. Our collaboration with R. P. Binzel to acquire rotational and shape statistics on km-size asteroids has continued with CCD observations of several small targets. Theoretical modeling of asteroid photometry led to publication of a review entitled "Application of Photometric Models to Asteroids" (Bowell *et al.* 1989b). Work on a spherical harmonics method of determining asteroid spin vectors (with K. Lumme and others) has resulted in submission of a paper to *Astronomy and Astrophysics*. Work on "photomorphography" (Kaasalainen *et al.* 1990) has continued.

(c) Our work next year will be given a boost by having Karri Muinonen aboard as a NASA Postdoctoral Fellow. Muinonen will work principally on the spatial distribution of asteroids. We will focus our astrometric effort in four areas: (1) LUKAS. We have just completed comparison of the two Trojan fields with digitized sky survey data. Further work should result in publication of several hundred 2-month-arc orbits, including perhaps 30 Trojan orbits. Software development is needed for linkage and identification that will cope with the rather large data throughput. We also hope to expand the scope of LUKAS to encompass the acquisition of spectra for faint asteroids. Four test objective-prism plates, two of which may contain as many as 300 physically diagnostic spectra, have been obtained. (2) GLAS. In tandem with LUKAS, we will be exploring ways of semi-automatically extracting long-arc orbits for many hundreds of relatively bright asteroids per year. This may entail a major upgrade of our PDS scanning microdensitometer. (3) With K. S. Russell and colleagues at Siding Spring, we will explore the creation of a special-purpose asteroid positional database. Initially, we will develop a method of extracting asteroid positions from the U.K. Schmidt Sky Survey, which is being digitized. The database will be an archive useful for asteroid identification and orbit linkage. We hope to carry out this research in conjunction with a search for Kuiper-belt comets, for which funding is being sought elsewhere. (4) CCD astrometry of comet P/Kopff in support of CRAF will commence this summer. CCD astrometry and photometry of selected asteroids (close-Earth-approachers, Chiron, targets for rotational statistics) will continue as before. Theoretical work on understanding asteroid brightness changes in terms of surface texture, albedo, and body shape will focus on two areas: (1) Lumme and colleagues will work on "photomorphography," the determination of three-dimensional body shape from disk-integrated photometry. (2) Muinonen and Lumme will further develop their idea that the opposition spike and negative polarization at small phase angles are caused by coherent backscattering.

(d) Bibliography

Bowell, E. (1989). [asteroid and comet observations]. *IAU Circular* Nos. 4767, 4908, 4911, 4927, and 4928.

Bowell, E. (1989). [asteroid and comet observations]. *Minor Planet Circular* Nos. 14288, 14292, 14560, 14733, 14994, 15030, 15175, 15181, 15325, 15331, 15443, and 15505.

Bowell, E. (1989). [asteroid identifications]. *Minor Planet Circular* Nos. 14328–14330, 14332, 14333, 14599, 14613, 14771, 14933, 14945, 15056,15057, 15387, 15393, 15423, and 15550.

Bowell, E. (1989). [asteroid orbits]. *Minor Planet Circular* Nos. 15053, 15230, 15241, 15242, 15381–15396, 15398–15408, 15410–15413, 15424, 15426, 15537–15540, 15542, 15547–15551, 15553, 15554, 15557, and 15560–15562.

Bowell, E. (1990). [asteroid and comet observations]. *Minor Planet Circular* Nos. 15607, 15629, 15811, 15820, 15821, 15967, 15977–15979, and 16149.

Bowell, E. (1990). [asteroid identifications]. *Minor Planet Circular* Nos. 15679, 15680, 15683, 15686, 15687, 15697, 15699, 15702, 15708, 15727, 15729, 15865, 15876, 16021, and 16229.

Bowell, E. (1990). [asteroid orbits]. *Minor Planet Circular* Nos. 15673–15675, 15678–15685, 15687, 15689–15693, 15697, 15699, 15701–15716, 15726, 15727, 15729, 15857–15863, 15865, 15870, 15873, 15879–15881, 15884, 15890–15892, 15895, 16002–16011, 16019, 16027, 16028, 16208–16210, 16221, 16223, 16229, and 16235–16237.

Bowell, E., Chernykh, N. S., and Marsden, B. G. (1989a). Discovery and follow-up of asteroids. In *Asteroids II* (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), pp. 21–38. University of Arizona Press, Tucson.

Bowell, E., Hapke, B., Domingue, D., Lumme, K., Peltoniemi, J., and Harris, A. W. (1989b). Application of photometric models to asteroids. In *Asteroids II* (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), pp. 524–556. University of Arizona Press, Tucson.

Bowell, E., Skiff, B. A., Wasserman, L. H., and Russell, K. S. (1990). Orbital information from motion vectors. In *Asteroids Comets Meteors III* (C.-I. Lagerkvist, H. Rickman, B. A. Lindblad, and M. Lindgren, eds.), pp. 19–24. Uppsala University, Sweden.

Bus, S. J. (1989). [comet observations]. *IAU Circular* No. 4804.

Bus, S. J. (1989). [asteroid identifications]. *Minor Planet Circular* Nos. 14331, 15396, 15404, 15405, 15407–15410, 15413, 15542, 15550, 15552, 15553, 15557, 15560, and 15561.

Bus, S. J. (1990). [asteroid identifications]. *Minor Planet Circular* Nos. 15684, 15701, 15703–15705, 15713–15716, 15879–15881, 15890–15892, 16011, and 16215.

Harris, A. W., Young, J. W., Contreiras, L., Dockweiler, T., Belkora, L., Salo, H., Harris, W. D., Bowell, E., Poutanen, M., Binzel, R. P., Tholen, D. J., and Sichao Wang (1989). Phase relations of high albedo asteroids: The unusual opposition brightening of 44 Nysa and 64 Angelina. *Icarus* **81**, 365–374.

Kaasalainen, M., Lamberg, L., and Lumme, K. (1990). Photomorphography of atmosphereless bodies: Asteroid shapes from lightcurves. In *Asteroids Comets Meteors III* (C.-I. Lagerkvist, H. Rickman, B. A. Lindblad, and M. Lindgren, eds.), pp. 115–118. Uppsala University, Sweden.

Roques, P. E. (1990). [comet observations]. *Minor Planet Circular* No. 15949.

Russell, K. S., and Bowell, E. (1990). Automated analysis of U.K. Schmidt plates to identify solar system objects. In *Asteroids Comets Meteors III* (C.-I. Lagerkvist, H. Rickman, B. A. Lindblad, and M. Lindgren, eds.), pp. 167–169. Uppsala University, Sweden.

Evolution of Large-Scale Plasma Structures in Comets: Kinematics and Physics

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(a) Strategy: The disconnection event or DE consists of the periodic loss of a comet's entire plasma tail and the growth of a new one. This spectacular phenomenon is not understood. The strategy is to assemble a data base of specific events studied in detail.

(b) Accomplishments: The basic data for this project consist of (1) the duplicate archive of IHW large-scale images (Boulder, CO) and (2) in situ solar-wind data. A major accomplishment has been the essential completion of the Boulder, CO duplicate archive. Substantial progress has been made in obtaining solar-wind data, but major blocks have not yet appeared in the literature.

The analysis of the 10 January 1986 DE is complete and will be published in the Proceedings of the July 1989 AGU Chapman Conference held at the University of Surrey.

Accurate disconnection times have been determined for five additional DEs and analysis continues. Observational material is sparse for the spectacular 22 February 1986 DE and special techniques will be developed.

(c) Anticipated Accomplishments: We expect to complete the analysis of three more DEs during the next year and that the broad outline of our results should be apparent.

(d) Publications: Two major papers are in press. (1) The detailed study of the 10 January 1986 DE by M. B. Niedner, J. C. Brandt, and Y. Yi, (2) The long awaited paper by J. C. Brandt: "Large Scale Structure of the Plasma Tail of Comet Halley During the 1985/1986 Apparition". In Comet Halley 1986, Ellis Horwood Ltd., 1990.

Infrared Observations of Small Solar System Bodies

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a) **OBJECTIVES** (*TASK 1*): To continue measurement and modeling of eclipse disappearance and reappearance curves for the Galilean satellites Europa and Ganymede to obtain a reliable estimate of the near sub-surface temperature. The IRTF at Mauna Kea Observatory will be used to obtain additional flux measurements at narrow-band wavelengths of 8.7 and 20 μm during several eclipse disappearances and reappearances of Europa and Ganymede. (*TASK 2*): To continue the study of minor amounts of volatiles such as methane, ammonia and carbon monoxide ices and clathrates on icy surfaces in the outer solar system, using high resolution spectra obtained with a multi-channel grating spectrometer. Specific targets are Europa, Enceladus, Ariel, Titania, and Triton.

b) **PROGRESS**: The 8.7-μm eclipse flux curves of Europa have been successfully matched with our solid-state greenhouse model and preliminary results suggest that Europa's near sub-surface temperature lies in the range 115-165K. Also the PI has obtained important new data on Europa that are being analyzed at present. The data are suggestive of yet another surface component, possibly a simple molecular ice. Newly obtained spectra of Enceladus suggest that it does not at present have ammonia or methane in detectable quantities on its surface. Spectra of Ariel were obtained at the last apparition of Uranus, but the S/N ratio is too low. I will obtain more data during the upcoming apparition of Uranus.

c) **PROPOSED WORK**: First, it is proposed to obtain additional observations of eclipse reappearances and disappearances of Europa and Ganymede, and to extend our analysis using solid-state greenhouse models that are more sophistcated than those used during the past year. Present models include a surface which is stratified in its thermal properties, and the details of the eclipse geometry include the Jovian peneumbra as well as the effect of the shadow of Jupiter sweeping across the face of a satellite during eclipse immersion and emersion. The data and the models will be used to improve the estimate of the extent of solid-state greenhousing on Ganymede and Europa. Second, it is proposed to observe Europa, Ariel, Dione, Rhea and Titania at even higher resolution than in previous observations to continue the study of volatile surface constituents.

d) **SUMMARY BIBLIOGRAPY**:

Matson, D. L. and R. H. Brown (1989). Solid-state greenhouses and their implications for icy satellites. *Icarus* 77, 67-81.

Brown, R. H. *et al*. (1988). Search for volatiles on icy satellites I: Europa. *Icarus* 74, 262-271.

Arecibo S-Band Radar Program

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a) General Objectives: The high powered 12.6cm wavelength radar on the 1000-ft Arecibo reflector is utilized for a number of solar system studies. Chief among these are: 1) Surface reflectivity mapping of the terrestrial planets and the moon. 2) High time resolution ranging measurements to the surfaces of the terrestrial planets. These measurements are used to obtain height profiles and scattering parameters in the equatorial region. They can also be used to test relativistic and gravitational theories. 3) Measurements of the orbital parameters, figure, spin vector and surface properties of asteroids and comets. 4) Observations of the Galilean Satellites of Jupiter and the satellites of Mars, Phobos and Diemos.

b) Past Twelve Months: Data taken during Venus' close approach to the earth in 1988 was reduced to images covering the latitude range 60°S to 66°N (excluding 10°S to 12°N) and the approximate longitude range 270° to 20°. With a resolution 1.5km they have provided the first detailed information about the southern hemisphere of the planet. Three mainbelt asteroids and five near-earth asteroids were successfully observed between Feb.'89 and Jan.'90 including 1989 PB. This near-earth object was 'imaged' with 300m resolution, the first good two dimensional images of an asteroid. 1989 PB has a bifurcated mass distribution and resembles two approximately kilometer-sized objects in close contact with each other. Io and the three icy Galilean satellites of Jupiter were observed in December and January. Six observations of Io provided good measurements of cross section and polarization ratios as a function of longitude. A successful, albeit weak, detection was made of Europa at 70cm indicating that its scattering properties at this wavelength are similar to the very unusual properties at 12cm.

c) Next Twelve Months: The cross polarized data for Venus from 1988 will be reduced to images in the next 12 months and used in conjunction with the current images in the expected sense to provide information about the diffuse scattering characteristics of volcanic flows and the 'bright' surrounds of probable impact craters. Observations of Mars to study scattering properties will be made in late 1990 plus what is expected to be the first successful observations at Arecibo of Phobos and Diemos. A small number of observations will be made of the icy Galilean satellites in early 1991 to improve the phase coverage for Doppler imaging. Four mainbelt asteroids will be studied and it is anticipated that one or more opportunities will occur for observations of close approaching small objects. Two comets will be observed in May and August. A program of high resolution lunar observations will begin in the summer of 1990.

d) Publications:

Coles, W.A. and Harmon, J.K., Propagation Observations of the Solar Wind Near the Sun", Astrophys. J., 337, 1023, 1989.

Harmon, J.K., Campbell, D.B., Hine, A.A., Shapiro, I.I. and Marsden, B.G., Radar Observations of Comet IRAS-Araki-Alcock, Astrophys. J., 338, 1071, 1989.

Campbell, D.B., Harmon, J.K. and Shapiro, I.I., Radar Observations of Comet Halley, Astrophys. J., 338, 1092, 1989.

Stofan, E.R., Head, J.W., Campbell, D.B., Zisk, S.H., Bogomolov, A.F., Rzhiga, O.N., Basilevsky, A.T. and Armand N., Geology of a Rift Zone on Venus: Beta Regio and Devana Chasma, Geological Soc. Am. Bulletin, 101, 143, 1989.

Campbell, D.B., Head, J.W., Hine, A.A., Harmon, J.K., Senske, D.A. and Fisher, P.C., Styles of Volcanism on Venus: New Arecibo High Resolution Radar Data, Science, 246, 373, 1989.

Vorder-Bruegge, R.W., Head, J.W. and Campbell, D.B., Orogeny and Large Scale Strike-Slip Faulting: Tectonic Evolution of Maxwell Montes, Venus, J. Geophys. Res., in press.

Ostro, S.J., Campbell, D.B., Hine, A.A., Shapiro, I.I., Chandler, J.F., Werner, C.L. and Rosema, K.D., Radar Images of Asteroid 1627 Ivar, Astron. J., in press.

Search for and Identification of Non-Ice Material on the Galilean Satellites Callisto and Ganymede

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a) **STRATEGY**: In the spectrum of the trailing hemisphere of Callisto the long wavelength side of the 2.0-μm ice band is suppressed apparently because of the presence of non-ice material in the optical surface. Low resolution spectra also suggest non-ice features in the 3 to 4-μm region. New observations at higher spectral resolution and higher signal-to-noise were planned with the hope of identifying spectral absorption features which could be attributed to minerals on the surface.

b) **ACCOMPLISHMENTS**: We requested and received time on the NASA Infrared Telescope Facility on Mauna Kea in both December 1989 and January 1990. Observations were made using the Cooled Grating Array Spectrometer with a grating which provided resolving powers near 300 for the wavelength regions of interest. Difficulties with both equipment failures and bad weather reduced our actual observing time by one-half. However, we were able to observe both leading and trailing hemispheres of Callisto and obtained excellent data from 1.9 to 2.45 μm and from 2.9 to 4.8 μm. Observations of Europa and Ganymede were also made with less wavelength coverage and with incomplete coverage of the leading vs trailing hemispheres. Ceres was also observed with the same wavelength coverage as Callisto. Preliminary data reduction has been made on all the data except for one night of observing. The digital data for this night was lost due to hardware problems with the tape drive at the IRTF. This data must be entered by hand from the hardcopy before reduction can proceed.

c) **ANTICIPATED ACCOMPLISHMENTS**: We plan to complete the data reduction for all observations so that they can be analyzed for absorption features that may be mineralogical in origin. Some theoretical unmixing models (after the method of Calvin and Clark, 1990) will be applied to the Callisto trailing hemisphere data to remove the contribution from ice and further constrain the nature of the non-ice material.

d) **SUMMARY BIBLIOGRAPHY**: Calvin, W. M. and R. N. Clark, Modeling the reflectance spectrum of Callisto 0.25 to 4.1 μm, submitted to Icarus, 1990.

Near-Infrared Observations of Venus

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DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography.)

a. Images of the Venus night side at wavelengths near 1.7 and 2.3 microns show bright features that move from east to west, in the direction of the atmospheric super-rotation (Allen and Crawford, 1984). We conducted coordinated near-infrared (NIR) imaging observations of the Venus night side from Kitt Peak and Mauna Kea Observatories during two-week periods in May and June 1988, before and after Venus passed through inferior conjunction. The imaging observations are being used to determine (1) the mechanisms which produce these features, (2) their level of formation, (3) the wind velocities at those levels, and (4) their implications for the Venus "greenhouse" mechanism.

b. Our results show that the NIR features are produced as thermal emission from the hot lower atmosphere leaks through partial clearings in the cooler middle or lower cloud decks. The brightest night-side features have 1.74 micron brightness temperatures near 480 K, while the darkest features have brightness temperatures near 425 K at that wavelength. This emission must originate from levels below 35 km in the Venus atmosphere. The feature contrasts are produced by horizontal variations in the optical thickness of the planet-wide cloud deck. The rotation period of the features is approximately 6.5 days, indicating equatorial westward wind velocities near 70 m/sec. The Pioneer Venus probes and the VEGA Balloons measured similar wind velocities in the convectively-unstable middle cloud region (48-58 km). These results are described in Crisp et al. 1989.

c. We propose to continue our analysis of the Venus night-side features to derive the first 2-dimensional description of the winds at levels below the cloud tops. We will also incorporate the observed feature contrast into our theoretical radiative transfer model to assess the impact partial cloudiness on the "greenhouse" mechanism. We are planning to obtain new imaging and spectroscopic observations of the night-side features when Venus passes through inferior conjunction in 1990 and 1991. The 1990 observing period will coincide with the Galileo flyby of Venus. Our ground-based observations complement those obtained by the Galileo NIMS experiment, which will provide only limited spatial and temporal coverage.

d. Crisp, D, W Sinton, K Hodapp, B Ragent, F Gerbault, J Goebel, R Probst, D Allen, K Pierce, K Stapelfeldt, "Near-Infrared Observations of The Venus Night Side," Submitted to <u>Science</u>.

Volatiles in the Outer Solar System

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Triton: New IR spectra of Triton in 1988 and 1989 confirmed the presence of N_2 and CH_4 in the solid state and a gaseous component of CH_4. Analysis of these data with new laboratory spectra of both methane and nitrogen showed that the atmosphere of Triton should be sufficiently transparent to permit Voyager to view the surface. Voyager detected the atmosphere of CH_4 and N_2 with a surface pressure of about 10 μbar, found haze, wind, and N_2 geysers, all consistent with the ground-based spectroscopy. Lightcurve data from the telescopic work showed the zonal homogeneity of Triton at the level of about 2% (total maximum amplitude of the rotational lightcurve). Additional pre-Voyager investigations considered the thermal structure and haze formation in the Triton atmosphere, using a modified Titan model as the basis for the study. The unexpectedly low temperature of Triton results in an atmosphere that is presently far less massive than that studied in the modeling work. Considerations of frost grain metamorphism in the N_2 ice of Triton's surface showed that crystals of many cm in scale should occur there, with important implications for spectral band formation and the solid-state greenhouse effect; Voyager results are still inconclusive on details of the condition of the solid N_2 on Triton.

Io: Analysis of previously unidentified absorption bands in the spectrum of Io (region 2.7-4 μm) by means of new laboratory data showed that two of the bands are H_2S complexed in a matrix of solid SO_2, and that two other bands are H_2O similarly complexed with SO_2. As determined by transmission spectra, the mixture best matching the Io spectrum is 3% H_2S and 0.1% H_2O in SO_2. Additional bands in the Io spectrum remain to be identified.

Chiron: Telescopic observations confirmed the "outburst" of 2060 Chiron in optical wavelengths, strongly indicating that this object known as an asteroid exhibits cometary behavior. This conclusion, based on photometry, was confirmed by the detection by Meech and Belton of a 5-arcsec coma of low surface brightness surrounding Chiron in 1989 and 1990. VRIJHK photometry, which revealed the nearly 1 magnitude brightening, also resolved the long-standing ambiguity about the fit of the visible spectrum to the infrared spectrum, confirming that Chiron's spectrum is very neutral, apparently placing it in the asteroid taxonomic class C. Chiron appears to be an ice-rich object darkened by C-class carbonaceous soil. It is the largest comet in the inner regions of the Solar System, with a nucleus about 200 km in diameter.

Asteroids: Telescopic observations of asteroids of various taxonomic and dynamical classes continue to clarify the compositions of specific objects and their connections with the meteorites. Topics under investigation include the asteroidal source of the olivine-rich meteorites, the nature of the C,P,D asteroids and their possibly carbonaceous surfaces, and the transition from S to A-class asteroids and its relationship to the issue of the differentiation of the S asteroids. Of special interest is the detection and study of three Earth-approaching Amor asteroids with basaltic surfaces analogous to Vesta.

Publications by D. P. Cruikshank, 1989-90.

B. Conrath and 15 coauthors, including D. P. Cruikshank. "Infrared Observations of the Neptunian System", **Science 246**, 1454-1459, 1989.

D. P. Cruikshank, "Dark Surfaces of Asteroids and Comets: Evidence for Macromolecular Carbon Compounds". **Adv. Space Res. 9**, (2)65-(2)71, 1989.

D. P. Cruikshank, "Triton, Pluto and Charon". **Adv. Space Res. 10**, (1)199-(1)207, 1990.

D. P. Cruikshank, R. H. Brown, L. P. Giver, and A. T. Tokunaga. "Triton: Do We See to the Surface?", **Science 245**, 283-286, 1989.

M. J. Gaffey, J. F. Bell, and D. P. Cruikshank. "Reflectance spectroscopy and asteroid surface mineralogy", in **Asteroids II**, R. P. Binzel and T. Gehrels, Eds., Univ. of Arizona Press: Tucson. 1990.

W. K. Hartmann, D. J. Tholen, K. J. Meech, and D. P. Cruikshank. "2060 Chiron: Colorimetry and possible cometary behavior", **Icarus 83**, 1-15, 1990.

N. L. Lark, H. B. Hammel, D. P. Cruikshank, D. J. Tholen, and M. A. Rigler. "The Brightness and Light Curve of Triton in 1987." **Icarus 79**, 15-22, 1989.

C. P. McKay, J. B. Pollack, A. P. Zent, and D. P. Cruikshank, "The Thermal Structure of Triton's Atmosphere: Pre-Voyager Models". **Geophys. Res. Let. 16**, 973-976, 1989.

F. Salama, L. J. Allamandola, F. C. Witteborn, D. P. Cruikshank, S. A. Sandford, and J. D. Bregman. "The 2.5-5.0 um spectrum of Io: Evidence for H_2S and H_2O frozen in SO_2. **Icarus 83**, 66-82, 1990.

B. A. Smith and 64 coauthors, including D. P. Cruikshank. "Voyager 2 at Neptune: Imaging science results", **Science 246**, 1422-1449, 1989.

A. P. Zent, C. P. McKay, J. B. Pollack, and D. P. Cruikshank. "Grain Metamorphism in Polar Nitrogen Ice on Triton", **Geophys. Res. Let. 16**, 965-968, 1989.

Spectroscopic Planetary Detection

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a. Strategy: One of the most promising methods for the detection of extra-solar planets is the spectroscopic method, where a small Doppler shift (~ 10 meters/sec) in the spectrum of the parent star reveals the presence of planetary companions. However, solar-type stars may show spurious Doppler shifts due to surface activity. If these effects are periodic, as is the solar activity cycle, then they may masquerade as planetary companions. The goal of this investigation is to determine whether the solar cycle affects the Doppler stability of integrated sunlight. Observations of integrated sunlight are made in the near infrared (~ 2 μm), using the Kitt Peak McMath Fourier transform spectrometer, with an N_2O gas absorption cell for calibration. We currently achieve an accuracy of ~ 5 meters/sec.

b. Accomplishments: We have been monitoring the apparent velocity of integrated sunlight since 1983. We initially saw a decrease of ~ 30 meters/sec in the integrated light velocity from 1983 through 1985, but in 1987-90 the integrated light velocity returned to its 1983 level. It is plausible that these changes are solar-cycle related, but it is still too early to be sure.

c. Anticipated accomplishments: Wallace et al. (1988, Ap.J. **327**, 399) found that the relative wavelengths of lines in integrated light were stable over the solar cycle, and they concluded that planetary companions were detectable. However, in a recent analysis of the extensive Mt. Wilson data, Ulrich and co-workers found evidence for large scale flows with amplitudes up to 50 meters/sec. Since such flows will affect all lines, they will not be seen in relative line shifts, but they may have a significant impact on spectroscopic planetary detection. However, our continued monitoring of integrated sunlight will detect such effects if they are present, since our measurements are absolute. When solar maximum has passed (>1991), we should know whether the changes seen earlier in integrated light velocity are periodic with the solar cycle, and to what extent large scale flows present a limitation to spectroscopic planetary detection.

d. Publications: "On the Apparent Velocity of Integrated Sunlight," D. Deming, F. Espenak, D. E. Jennings, J. W. Brault and J. Wagner 1987, Ap.J. **316**, 771-787.

Occultation Studies of the Solar System

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a. Strategy: Because of their high spatial resolution, stellar occultations have proven extremely effective for learning about planetary upper atmospheres, asteroids, and planetary rings. Our occultation program at M.I.T. involves **(i)** identifying the scientific questions that can be answered by occultation events, **(ii)** predicting the zone of visibility for the useful events, **(iii)** maintaining and improving a high-speed CCD camera for observing occultations, **(iv)** obtaining the observations, and **(v)** reducing the data and interpreting the results.

b. Accomplishments: Our accomplishments during the past year include **(i)** development of an inversion technique for stellar occultation data that is suitable for small bodies (atmospheric scale height is a significant fraction of the body's radius); **(ii)** use of this technique to obtain temperature profiles of Pluto's atmosphere, which confirmed that a steep temperature gradient is an acceptable model for explaining the sharp drop in Pluto's occultation light curve; **(iii)** a reanalysis of Walker's occultation data, which yielded a stringent lower limit of 600 km on Charon's radius; and **(iv)** preparation of a software package that we are now using to scan CCD frames for Pluto occultation candidates. This method can find candidates somewhat fainter than possible with current photographic searches, but bright enough to produce high-quality occultation data if the path of the event includes a telescope of a few meters in aperture.

c. Anticipated Accomplishments: We are beginning comparative investigation of the atmospheres of Pluto, Titan, and Triton with stellar occultations. The atmospheres of these bodies form a third broad category of planetary atmospheres, considering the other two categories to be terrestial planet and Jovian planet atmospheres. Identification of these occultations, is in progress, to be followed by observations and analysis. An important part of our program is the development of CCD techniques for occultation predictions and observations.

d. Publications:

Baron, R. L., R. G. French, and J. L. Elliot 1989. The oblateness of Uranus at the 1-μbar level. *Icarus* **78**, 119-130.

Elliot, J. L., and L. A. Young 1990. Limits on the radius and possible atmosphere of Charon from its 1980 stellar occultation. *Icarus* (submitted).

Elliot, J. L., E. W. Dunham, A. S. Bosh, S. M. Slivan, L. A. Young, L. H. Wasserman, and R. L. Millis 1989. Pluto's atmosphere. *Icarus* **77**, 148-170.

Planetary Spectroscopy

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Uwe Fink

a. **Strategy:** Our effort is divided into instrumentation and observational research. In the area of instrumentation our primary objective is the maintenance and slow improvement of our CCD camera and data acquisition system for continuing use of any interested LPL user. The main goal of our observational research is CCD spectroscopic and imaging studies of the solar system in support of spacecraft investigations. Our studies include the physical behavior of comets, the atmospheres of the gaseous planets, and the solid surfaces of satellites and asteroids.

b. **Accomplishments:** We acquired a new CCD controller that will allow sub-array readout and binnning and will replace our aging and thus breakdown prone present controllers. Integrating this system into our present data-acquisiton computers required considerable work and is almost completed but not quite finished. We submitted over 200 flat-fielded and absolutely calibrated BVRI and H_2O^+ images plus a large number of spectra to the IHW watch archive. This exceedingly time consuming and tedious job was carried out by Al Schultz. Our system was again used heavily by other LPL groups: E. Karkoschka who now finished his thesis on Saturn; Kent Wells and Bashar Rizk to study water vapor lines on Venus; Kent Wells and Kevin Garlow to try to detect lighting on Venus; and Ann Tyler to study Na emission from the Moon and Mercury. Graduate student Mike DiSanti completed his Ph.D. dissertation on the H_2O^+ spatial distribution in comet P/Halley. A paper giving the results of this work is in press: Icarus, **84** 4242-4262. We were able to produce the first quantitative maps of the pure H_2O^+ distribution and were able to derive an ion accleration of ~0.1g down the tail. A paper on "The production rate and spatial distribution of H_2O for comet P/Halley" is in press in Ap.J. This paper deduced the H_2O production rate of comet P/Halley from 43 exposuress during the period 1985 August to 1986 June, using the OI ^1D line at 6300A. A pre-perihelion fit to the H_2O production rate, $Q(H_2O)=4.36x10^{29} \cdot r^{-2.59}$ was obtained. The post-perihelion enhancement was approximately a factor of 1.8. We completed a paper on "A composition comparison between comet P/Halley and P/Brorsen-Metcalf" which was submitted to Icarus. The production rate of NH_2 was down by a factor of 3 and that of C_2 and CN by about a factor 2 when compared to the H_2O production rates of their respective comets. The dust emission in P/Brorsen-Metcalf was weaker by a factor of 20. On the observational side we were able to attain spectral data on a number of other comets in addition to P/Brorsen-Metcalf inter al.: SW1, Gehrels2, Clark, SW3, and Wild4.

c. **Anticipated Accomplishments:** Graduate student W. Grundy is in the process of analyzing new high quality spectra of Triton that show a weak 8900A methane absorption. We are scheduled for 8 nights in May to obtain improved spectra of Triton as well as comparative data with Pluto. In collaboration with Mike Combi, we will continue our analysis of OI, NH_2, C_2, and CN for comet P/Halley. We also are planning to continue our spectroscopic observations of additional comets in order to determine compositional differences for a large sample. We will pay particular attention to comet Austin and plan to carry out an analysis for this comet similar to P/Brorsen-Metcalf.

Surveying of the Solar System

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Tom Gehrels

a. <u>Strategy</u>: Some populations of objects in the solar system are poorly known, and the long-range goal of this program is to improve that situation. For instance, the statistics of Trojan asteroids are uncertain, while previous Palomar-Leiden surveying indicates there is an appreciable systematic difference between the L-4 and L-5 regions. We are working together with Drs. C. J. and I. van Houten of the Leiden Observatory in a continuation of the Palomar-Leiden Survey to investigate the statistics of Trojan asteroids. We are also developing new techniques of sky surveillance by scanning with CCD.

b. <u>Accomplishments</u>: A 320 x 512 pixel CCD has been in operation, 1983-1988, on a telescope that is dedicated during the dark half of each month to sky surveillance, namely the Spacewatch Telescope which is the 91-cm Newtonian reflector of the Steward Observatory on Kitt Peak. We have written a summary and analysis of our previous work and present status in a paper entitled "Various Modes of Using Charge-Coupled Devices," by T. Gehrels, R. S. McMillan, J. V. Scotti, M. L. Perry, and D. L. Rabinowitz. Results are given for searches of gamma-ray bursters, space debris, satellites, comets, cometesimals, the tenth planet, and various types of asteroids. Routine astrometry with the transit method is done for comets and asteroids, with a precision better than $\pm$ 0.7 arcsecs. We are presently using a Tektronix 2048 x 2048 CCD, "thick," front-illuminated, with pixel size 27 x 27 microns. Apollo asteroid 1989UP was discovered with it. It has a Solbourne work station computer which has a Sun unix operating system running on a multiple CPU architecture; this system can process multiple programs in parallel. Through a cooperative program with the Indian Institute of Astrophysics, a 385 x 576 CCD was initiated in the scanning mode at the 2.4-m Bappu reflector of the Kavalur Observatory.

c. Anticipated Accomplishments: Software for automatic recognition of fast-moving objects is coming on-line. We will increase the rate of scanning, eventually with an improved CCD and further additions to the computer system.

d. Publications: "The 1977 Palomar-Leiden Trojan Survey," I. van Houten-Groeneveld, C. J. van Houten, M. Wisse-Schouten, C. Bardwell and T. Gehrels, Astron. Astrophys. 224, 299-302, 1989.

"Drift Scanning with a TK2048 CCD," T. Gehrels, R. S. McMillan, J. V. Scotti, and M. L. Perry, A. S. P. Conf. Series, **6**, CCDs in Astronomy, ed. G. H. Jacoby (Provo: Brigham Young Univ. Press), 1989.

Asteroids II, R. P. Binzel, T. Gehrels, and M. S. Matthews, eds., Univ. of Ariz. Press, 1989.

"Search for Near-Earth Asteroids with the Spacewatch Camera," T. Gehrels, 1990, Annual Report (Tucson, AZ: NASA/UA Center for the Utilization of Space Resources).

Submillimeter Heterodyne Receiver for the Caltech Submillimeter Telescope

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Samuel Gulkis

a) The objective of the task is to design and build a submillimeter (600-700 GHz) heterodyne radiometer to investigate spectral lines in planetary and satellite atmospheres, and comets. The instrument will be used as a facility instrument at the Caltech Submillimeter Observatory on Mauna Kea.

b) Progress and accomplishments - The waveguide mixer mount has been designed and fabricated. It is currently undergoing polishing to achieve the final dimensions. The mount uses a split block design. Pb-alloy SIS tunnel junctions are currently being fabricated at Bell Laboratories, and NbN tunnel junctions are under development at JPL. Preliminary design of the IF impedance transformers has been accomplished.

   The low-noise cooled HEMT IF amplifier and power supply have been assembled. The room temperature IF system has been built and tested. The SIS mixer bias supply has been built but not fully tested. Most of the external dc and IF electronics has been assembled in a rugged package designed to mount on the cryostat.

   The phase-lock system for the local oscillator source is being designed and constructed. The procured local oscillator sources have measured powers of about 40 microwatts, sufficient to drive the mixer.

c) The complete radiometer operating at 626 GHz should be assembled by the end of FY1990. During the next year we intend to mount the system on the CSO telescope on Mauna Kea and begin system tests.

d) Publication - W.R. McGrath, K. Jacobs, M. Frerking, R.E. Miller, J. Stern, H. LeDuc, B. Hunt, "Development of a 600-700 GHz SIS Receiver, presented at the First International Symposium on Space Terahertz Technology, University of Michigan (March 1990).

Infrared Observations of Comets

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Martha S. Hanner

A). Selected comets are observed in the infrared with the NASA IRTF and other telescopes as appropriate. The scientific objectives are to characterize the thermal emission from the dust coma, derive dust production rates, study the silicate features near 10 and 20 microns, and detect changes in grain size or composition with heliocentric distance as well as differences among comets. In a few cases of low dust activity, the comet nucleus can be directly detected in the infrared and its size and albedo determined.

B). Accomplishments: 25 comets have been observed under this program. The data base is being used to obtain the average properties of comet dust and to derive physical information about selected individual comets. Progress in 1989 includes: 1) A review paper on infrared techniques for comet observations has been written with A. Tokunaga for the proceedings of the Bamberg Comet Conference. The review includes a comparison of the Arizona, Mauna Kea, and Minnesota/Wyoming infrared photometric systems. 2) 10μm CVF spectra of Comet P/Brorsen-Metcalf were obtained at the IRTF. In contrast to P/Halley, no silicate feature was present; the nucleus is probably less active than Halley. A paper is in preparation. 3) Paper on Comet Bradfield (1987s) was written. This long-period comet has a silicate feature very similar to that in P/Halley. 4) Work was begun on modeling the light interaction by large grains, to interpret the comet data.

C). 1990 Plans: 1) IRTF observations of Comet Austin (1989) and short-period comets P/Encke and P/HMP are planned, both photometry and 10μm spectrophotometry, to investigate differences in dust properties between new and short-period comets with small perihelion distance. 2) Measurement of accurate standard star magnitudes for the 7.8 - 12.5μm IRTF silicate filters is in progress. Lack of accurate magnitudes has delayed interpretation of P/Giacobini-Zinner data, where a small silicate feature may be present. 3) Calculations of the scattering and emission by irregular particles continue; results are being applied to interpret the cometary data. 4) Papers on P/Giacobini-Zinner, P/Brorsen-Metcalf, and P/Tempel 2 are in progress.

D). Publications:

Hanner, M.S. and Newburn, R.L. (1989cl). Infrared photometry of Comet Wilson (1986l) at two epoches. *Astron. J.*, **97**, 254-260.

Hanner, M.S., Newburn, R.L., Gehrz, R.D., Harrison, T., Ney, E.P. and Hayward, T.L. (1990). The infrared spectrum of Comet Bradfield (1987s) and the silicate emission feature. *Astrophys. J.*, **348**, 312-321.

Hanner, M.S. and Tokunaga, A.T. (1989). Infrared techniques for comet observations. In *Comets in the Post-Halley Era*, ed. R.L. Newburn, J. Rahe, M.M. Neugebauer.

Veeder, G.J., Hanner, M.S., Matson, D.L. and Tedesco, E.F. (1989). Radiometry of near-earth asteroids, *Astron. J.*, **97**, 1211.

Search for Planet X

U.S. Naval Observatory

R.S. Harrington

The strategy is simple and twofold. First, numerical simulations of ten-planet solar systems are used to determine what orbital characteristics are required of a tenth planet to produce perturbations in the orbits of Uranus and Neptune that resemble the observed ones. These will in turn be used to establish a region of the sky in which the planet might be located. Second, plates will be taken of this region, using a standard astrograph, on successive nights, and these plates will be blinked on a blink comparator in Washington.

The simulations have been completed, and they indicate a reasonably compact region centered on the constellation Centaurus. Being fairly far South, this region will have to be covered from our station on Black Birch Mountain in New Zealand, where we have a twin 20-cm astrograph. In order to easily estimate the distance to any moving object, the field should be photographed at opposition, when the motion is predominantly reflex terrestrial motion. This region is in opposition in April and May, and that is the time we have set aside this year for observing, with blinking therefore in May and June.

Our hoped-for accomplishment is to find a tenth planet. If we don't, we either a)looked in the wrong place, b)it is fainter than anticipated, c)it was somehow hidden at the time of observation, or d)it isn't there!

Table Mountain Observatory Support to Other Programs

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Alan W. Harris

a. The Table Mountain Observatory (TMO) facilities include well equipped 24" and 16" telescopes, with 40" (owned by Pomona College) and 48" (JPL) telescopes due for completion soon. This task is to provide operational support (equipment maintenance, setup, and observing assistance) at TMO to other programs.

b. The program currently most heavily supported by this grant is the asteroid photometry program directed by A. Harris. During 1989, about 20 asteroids were observed, including a newly-discovered earth-crossing asteroid, 1989 PB. The photometric observations are used to derive rotation periods, estimate shapes and pole orientations, and to define the phase relations of asteroids. The observations of 1989 PB are of particular interest, as this is the asteroid revealed by radar observations to be a "contact binary". Six papers reporting results of asteroid photometry were published in 1989. Comet observations are made with the narrow band camera system of David Rees, University College London. Observational support and training was provided to students and faculty from the Claremont Colleges for variable star observing programs.

c. We propose to continue the asteroid program, with emphasis on measuring phase relations of low and high albedo asteroids at very low phase angles, and supporting collaborative studies of asteroid shapes. Efforts will be made to observe occultations by asteroids, and to obtain lightcurves so that the rotation phase at the time of occultation will be known. Asteroids which are planned for radar observations will be given special attention, as the combination of radar and photometric data is much more valuable than either observation separately. The Rees narrow band camera is at TMO and will be used as comet targets become available. Plans are already set to observe Comet Austin extensively in May, 1990. Other observing programs will be supported as scheduled on the telescopes, as resources permit.

PUBLICATIONS

Bus, S.J., E. Bowell, A.W. Harris, and A.V. Hewitt (1989). 2060 Chiron: CCD and electronographic photometry. Icarus 77, 223-238.

Hahn, G., P. Magnusson, A.W. Harris, J.W. Young, L.A. Belkora, N.J. Fico, D.F. Lupishko, V.G. Shevchenko, F.P. Velichko, R. Burchi, G. Ciunci, M. DiMartino, and H. Debegogne (1989). Physical studies of Apollo-Amor asteroids: UBVRI photometry of 1036 Ganymed and 1627 Ivar. Icarus 78, 363-381.

Harris, A.W. and J.W. Young (1989) Asteroid lightcurve observations from 1979-1981. Icarus 81, 314-364.

Harris, A.W., J.W. Young, E. Bowell, L.J. Martin, R.L. Millis, M. Poutanen, F. Scaltriti, V. Zappala, H.-J. Schober, H. Debehogne, and K.W. Zeigler (1989) Photoelectric observations of asteroids 3, 24, 60, 261, and 863. Icarus 77, 171-186.

Harris, A.W., J.W. Young, L. Contreiras, T. Dockweiler, L. Belkora, H. Salo, W.D. Harris, E. Bowell, M. Poutanen, R.P. Binzel, D.J. Tholen, and S. Wang (1989) Phase relations of high albedo asteroids: The unusual opposition brightening of 44 Nysa and 64 Angelina. Icarus 81, 365-374.

Millis, R.L., L.H. Wasserman, E. Bowell, A.W. Harris, J.W. Young, M.A. Barucci, R.M. Williamon, P.L. Manley, D.W. Dunham, R.W. Olson, W.E. Baggett, and K.W. Zeigler (1989) The diameter, shape, albedo, and rotation of 47 Aglaja. Icarus 81, 375-385.

Palomar Planet-Crossing Asteroid Survey (PCAS)

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Eleanor F. Helin

STRATEGY: (OBJECTIVES) A systematic search for planet-crossing asteroids is being conducted with the 0.46 m Schmidt telescope at Palomar to increase the number of known asteroids to improve estimates of their population and size distribution. The program has expanded as a result of interest in their origins, their compositions as candidates for spacecraft missions, and their potential as resource material in space. International cooperation by observers around the world has contributed significantly to the search.

ACCOMPLISHMENTS: 11 Near-Earth Asteroids (NEA's), 6 Apollos and 5 Amors, were discovered this past year, an exceptional achievement reflecting continued improvement of the program and the efforts of everyone involved. Two hundred and one other new asteroids were also found, reported and given designations. And five new comets, 3 periodic and 2 parabolic, were discovered plus the recovery of Comet P/Brorsen-Metcalf added to this extraordinary year's accomplishments. The discovery of a supernova by SURF students assisting during the summer was an additional bonus. Several of the NEA'S made close approaches to the Earth during the year. The orbit of Apollo 1989 PB, found 10 days before closest approach, was sufficiently refined to allow detailed radar observations (S. Ostro) to be made during closest approach. These observations, the first 2 dimensional images of an NEA, revealed a "contact binary asteroid," perhaps the result of a low velocity impact between two objects. Asteroid 1989 ML has the smallest semi-major axis of any known Amor. Its present orbit neither crosses the orbit of the Earth or that of Mars. Considering its relative position with respect to Earth, its low inclination and low eccentricity, it appears to be an excellent mission candidate. Of the 201 other asteroids discovered, 30 are high inclination objects, considered to be a probable source of the NEA's, and of particular interest to this program. In addition, 28 asteroids found during prior apparitions were recovered and numbered, 5 of them NEA's: (3988) 1986 LA, (4015) 1979 VA, (4034) 1986 PA, (4055) 1985 DO2 and (4197) 1982 TA.

ANTICIPATED ACCOMPLISHMENTS: Further progress in the automated identification and measurement procedures, using a microdensitometer and a VAX 730, is anticipated. This will provide an improved capability to increase and accelerate discovery of all classes of asteroids. Already, improvement in measurement techniques has allowed more time for detailed review of data which has led to the greatest number of NEA/comet discoveries in the history of the PCAS program. Along with our primary NEA program, we will continue our studies and analysis of inner-belt (Hungaria and Phocaea) asteroid regions.

PUBLICATIONS

Planet-Crossing Asteroid Survey (PCAS)

Helin, E. F. (1988) "Discovery, Recovery and Physical Observations of (3757) 1982 XB: A Prime Mission Candidate", Asteroids II Conference Proceedings, Tucson.

Helin, E. F. and B. P. Roman (1989) "Interesting Dynamical Aspects of 1989b, a New Short Period Comet", Lunar and Planetary Science Conference XX Proc., March, 1989.

Helin, E. F. and B. P. Roman (1989) "Recovery of Halley-Class Periodic Comet Brorsen-Metcalf (1989o)", AAS, DPS, Providence, R.I., Nov. 1989.

Helin, Eleanor F. and Brian P. Roman (1989) "High Inclination Inner-Belt Asteroids: Hungarias and Phocaeas", in Asteroids, Comets, Meteors III, (Lagervist, C-I., Lindblad, B.A., Lundtedt, H., and Rickman, H. Eds), pp.105-108.

Helin, E. F. and R. S. Dunbar (1990) "Search Techniques for Near-Earth Asteroids", Vistas in Astronomy, V. 33, No. 1, pp. 21-37.

Helin, E.F., Roman, B.P., Alu, J.T. (1990) "Comets Discovered by PCAS in 1989," Lunar and Planetary Science Conference XXI Proc., March, 1990.

Discovery and Astrometric Position Publications

International Astronomical Union Circulars:

1989: 4699,4701,4704,4705,4714,4748,4762,4766,4776,4779,4804,4807, 4823,4831,4846,4847,4857,4859,4869,4872,4875,4878,4886,4887

1990: 4951,4952,4954

Minor Planet Circulars:

1989: 14081-087,14125-127,14232-235,14288-292,14384-391,14429-432, 14520-522,14553-560,14668-671,14726-732,14848-864,14994-15030, 15130-135,15175-181,15283-287,15325-330,15440-443,15499-504

1990: 15603-607,15625-629,15811-820

Interiors and Atmospheres of Outer Planets

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W.B. Hubbard

a) This theoretical/observational project constrains structure of outer planets atmospheres and interiors through observational data. The primary observational tool is through observations of occultations of stars by outer solar system objects, which yield information about atmospheric temperatures and dynamics, and planetary dimensions and oblateness. The theoretical work relates the data to interior structures in a variety of ways. (b) We successfully observed the 3 July 1989 occultation of 28 Sgr by Saturn and its rings from eight stations in the western hemisphere, including southwestern North America, Hawaii, and Chile. We also observed the occultation of the same star by Titan from two sites in Israel and one site in Italy. The mesospheric temperatures of both Saturn and Titan were measured in a region not studied by Voyager. Correlated scintillations seen at several stations provide information on the upper-atmosphere dynamics of both bodies. A preliminary study of Saturn ring timings shows that the positions of ring edges can be determined from the occultation data set to precision of $\sim$ 1 km. An occultation of a K=7 star by Jupiter on 13 December 1989 was successfully observed with excellent signal/noise using a $2-\mu$m array. This observation will provide the first direct measurement of Jupiter's mesospheric structure since 1971. (c) We plan no major efforts to observe occultations in 1990. Most of the year will be devoted to reducing and analyzing the prodigious amount of occultation data ($\sim$ 1 gigabyte) gathered during 1989. The analysis will yield detailed information on the structure and shape of the upper atmospheres of Jupiter, Saturn, and Titan. Older Neptune occultation data will be searched for evidence of ring arcs using the improved knowledge of Neptune's pole and ring system from the 1989 Voyager encounter.

d)

Hubbard, W.B., Models of Jovian Planets, in *Simple Molecular Systems at Very High Density*, (ed. P. Loubeyre, A. Polian, and N. Boccara), New York: Plenum, 1989.

Hubbard, W.B., Structure and Composition of Giant Planet Interiors, in *Origin and Evolution of Planetary and Satellite Atmospheres*, (ed. S.K. Atreya, J.B. Pollack, and M.S. Matthews), p. 539, 1989, University of Arizona Press.

Hubbard, W.B., and Marley, M.S., Optimized Jupiter, Saturn, and Uranus Interior Models, *Icarus*, **78**, 102, 1989.

Millis, R.L., Wasserman, L.H.,Franz, O.G., Bowell, E., Nye, R.A., Thompson, D.T.,White, N.M., Hubbard, W.B., Eplee, R.E., Lebofsky, L.A., Marcialis, R.L., Greenberg, R.J., Hunten, D.M., Reitsema, H.J., Bochen, Q., Dunham, D.W., Maley, P.D., Klemola, A.R., and Yeomans, D.K., Observations of the 8 December 1987 Occultation of AG + 40°0783 by 324 Bamberga, *Astron. J.*, **98**, 1094, 1989.

Interiors of the Giant Planets

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W.B. Hubbard

(a) This theoretical/observational project constrains interior structure of Jovian planets through observational data. The primary observational tool is through observations of occultations of stars by outer solar system objects, which yield information about atmospheric temperatures and dynamics, and planetary dimensions and oblateness. The theoretical work relates the data to interior structures in a variety of ways. (b) We successfully observed the 9 July 1988 Neptune occultation, and completed analysis of coincident Neptune occultation data from 1987. The 1987 data show evidence for a partial ring at a radius of 35000 km. The Neptune upper-atmosphere scale height remains very reproducible at about 50 km. We published, with David Tholen, a theory for the optics of Pluto-Charon mutual events, showing that ray optics are adequate for the analysis, together with data confirming the theory. We analyzed a data set from Hobart, Tasmania for an occultation by Pluto (June, 1988) and derived a new theory for refractive defocusing by a planet with an atmospheric scale height which is non-negligible compared with the planet's radius. The Hobart data are consistent with a pure methane atmosphere at a temperature of about 61 K and a surface pressure of about 5 microbars. (c) We plan a major effort to observe the 3 July 1989 Saturn occultation from several stations in Arizona, Chile, and Hawaii. This grant will support major parts of the data analysis, which will be directed at studies of the ring system, the atmosphere, and detailed planetary shape via study of central flash data. For the first time, use of an area detector should provide the angular distribution of the refracted starlight as well as its total flux. We will continue to carry out multistation observations of favorable Neptune occultations. We will study the existing Neptune occultation data base to draw conclusions about the existence of gravity waves in the Neptunian atmosphere and to obtain more information about the structure of Neptune's high atmosphere for comparison with Voyager encounter data.

(d) **1988 publications in refereed scientific journals:**

Hubbard, W. B., Hunten, D. M., Dieters, S. W., Hill, K. M., and Watson, R. D. (1988). Occultation evidence for an atmosphere on Pluto, *Nature* **336**, 452-454.

Hubbard, W. B., Lellouch, E., Sicardy, B., Brahic, A., Vilas, F., Bouchet, P., McLaren, R. A., and Perrier, C. (1988). Structure of scintillations in Neptune's occultation shadow, *Astrophys. J.* **325**, 490-502.

Narayan, R., and Hubbard, W. B. (1988). Theory of anisotropic refractive scintillation -- application to stellar occultations by Neptune, *Astrophys. J.* **325**, 503-518.

Tholen, D. J., and Hubbard, W. B. (1988). No effect of diffraction on Pluto-Charon mutual events, *Astronomy and Astrophysics* **204**, L5-L7.

Radiative Transfer in Planetary Atmospheres

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William M. Irvine

a. Theoretical techniques and observations at millimeter wavelengths are combined to study the atmospheres of planets and comets, planetary and satellite regoliths, and planetary rings.

b. Theoretical study of the reflection of light by planetary and satellite regoliths continued, including the development of new methods of calculating radiative transfer in rough surface layers and the refinement of techniques for determining the distribution of slopes in such a regolith by "statistical photoclinometry". The environment of young stellar objects was also investigated from a theoretical analysis of the hydrogen line spectrum. Radioastronomical observations resulted in the detection of a new interstellar molecule, C_4Si; in the past such detections have led to the proposal that such molecular species may be constituents of cometary comae, a result which seems to have been confirmed in the case of $C_3H_3^+/C_3H_2$, where the former has been detected in Comet Halley and is the expected precursor of the latter. The study of the physics and chemistry of the "proto-solar nebula" in the core of the L134N molecular cloud continued, revealing distinctive gradients in chemical composition. Both theoretical and observational studies of comets continued, including particularly millimeter and centimeter wavelength molecular emission from cometary comae.

c. The study of radiative transfer in planetary and satellite regoliths and cometary nuclei will continue, including application to data obtained on the USSR Phobos mission. Millimeter and centimeter wavelength observations of comets will be carried out as bright comets appear; specifically, observations of Comet Austin are planned at the University of Massachusetts-operated FCRAO, at NRAO, and at the University of California's Hat Creek Radio Observatory. The NRAO observations will concentrate on the OH radical, while the other studies will begin with searches for emission from HCN at millimeter wavelengths.

d. A list of publications for 1989 is attached.

Publications for the Planetary Astronomy Program for 1989

Alonso-Costa, J.L. and Kwan, J., "Hydrogen Line and Continuum Emission in Young Stellar Objects. II. Theoretical Results and Observational Constraints", Ap. J., 338, 403 (1989).

Muinonen, K., Lumme, K., Peltoniemi, J., and Irvine, W.M., "Light Scattering by Randomly Oriented Crystals", Applied Optics, 28, 3051-3060 (1989).

Muinonen, K., "Scattering of Light by Crystals: a Modified Kirchoff Approximation", Applied Optics, 28, 3044 (1989).

Ohishi, M., Kaifu, N., Kawaguchi, K., Murakami, A., Saito, S., Yamamoto, S., Ishikawa, S., Fujita, Y., Shiratori, Y., and Irvine, W.M., "Detection of a New Circumstellar Carbon-Chain Molecule, C_4Si", Ap. J. (Lett.), 345, L83 (1989).

Peltoniemi, J., Lumme, K., Muinonen, K., and Irvine, W.M., "Scattering of Light by Stochastically Rough Particles", Applied Optics, 28, 4088 (1989).

Schloerb, F.P., "The Large Deployable Reflector", in The Formation of Planetary Systems, ed. H.A. Weaver and L. Danly, STSI Symposium Series #3 (1989).

Swade, D.A., "Radio Wavelength Observations of the L134N Molecular Core", Ap. J. Suppl., 71, 219 (1989).

Swade, D.A., "The Physics and Chemistry of the L134N Molecular Core", Ap. J., 345, 828 (1989).

Tacconi-Garman, L., "Kinetic Models of Cometary Comae", Ph.D. Dissertation, University of Massachusetts (1989).

Laboratory Simulation of the Surface of Halley's Comet

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William M. Jackson

a) Laboratory studies are performed on the photochemistry of ices in an effort to determine under what conditions free radicals can be released directly in the gas phase. This information is used along with a theoretical model to see if photolysis of grains can be responsible for some of the observed radicals in comets.

b) Ices such as C_2N_2, $C_2(CN)_4$, and BrCN have been used. The first two compounds are known to undergo photolysis via an indirect mechanism in the gas phase, while the later compound undergoes direct dissociations under the same circumstances. The preliminary results show that CN radicals are only observed in the gas phase from BrCN and not from the other two molecules. This suggest that only in the case of indirect dissociation will free radicals be produced in the coma from grains. Theoretical calculations are in progress to determine the rate at which a grain can produce free radicals in the gas phase. The results of these calculations will be compared with the Halley observations of CN jets and rays to determine if this model explains the observed phenomena.

c) In the coming year, the experiments will be continued in the new apparatus that is under construction. With this apparatus the angular dependence of the radical emission will be determined. A pulsed valve will be used to replace the ice with a fresh layer between laser shots. Both of these experiments should give us additional insight into the photochemical release mechanism. The wavelength will be changed to 157 nm so that we can determine how adding more energy per photon affects the emission rate. The theoretical model will be expanded to include other ices such as water, HCN, NH_3, C_2H_2, etc.

d) Gregory Moller and William M. Jackson, "Laboratory Studies of Polyoxymethylene: Application to Comets", ICARUS, 84 (1990)

High Resolution Infrared Planetary Astronomy Using Cryogenic Grating Spectrometers

Planetary Systems Branch, Code 693
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Donald E. Jennings

Description: Our purpose in this program is to observe the infrared spectra of planets and comets at the highest possible spectral resolution and sensitivity. Molecular lines formed in planetary atmospheres are narrow, requiring resolving powers near 10^5 to completely resolve lineshapes and rotational structure. Resolution and sensitivity are required in ground-based studies of atmospheric composition, chemistry and dynamics because weaker, obscured lines are often the most important. Moreover, high spatial resolution is generally needed to map a planet, and this in turn requires high sensitivity. Our primary goal is to follow up results from Voyager, Viking, and other missions, and to prepare a basis for future missions. Accomplishments in this program include 0.01 cm^{-1} spectroscopy of Jupiter, Mars and Venus with our cryogenic grating postdisperser attached to the FTS's at the Kitt Peak McMath and 4-meter telescopes. Ethane and acetylene were observed in Jupiter at 12 to 14 micron, and deuterated water was observed on Mars at 3.7 microns. In addition, we imaged the equatorial region of Jupiter at 8-12 microns to search for thermal structure and oscillations.

Publications

1. "A search for p-mode oscillations of Jupiter: serendipitous observations of non-acoustic thermal wave structure," D. Deming, M. Mumma, F. Espenak, D. Jennings, T. Kostiuk, G. Wiedemann, R. Loewenstein, and J. Piscitelli, Astrophys. J., 343, 546 (1989)

2. "Postdispersion system for astronomical observations with Fourier transform spectrometers in the thermal IR," G. R. Wiedemann, D. E. Jennings, R. A. Hanel, V. G. Kunde, S. H. Moseley, G. Lamb, M. D. Petroff and M. G. Stapelbroek, Applied Optics 28, 139 (1989).

3. "High Resolution FTS in Astronomy at 7 to 15 Microns," D. E. Jennings, in High Resolution Fourier Transform Spectroscopy, Optical Society of America Technical Digest Series, 46, 74 (1989).

Temporal Monitoring of Active Comets

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a). The comets are notoriously variable and unpredictable objects. Curiously, very little quantitative work has been done on the temporal variations in comets. We seek to remedy this deficiency. Time-series charge coupled device photometry and spectro-photometry are together used to study variations occurring on timescales from minutes to weeks. The scientific objectives are (1) to determine the influence of nucleus rotation on the time-dependent morphology of the inner coma, and (2) to understand stochastic processes which lead to "outbursts" in comets.

b). A major result of the first year of funding was the publication of our work on comet P/Schwassmann Wachmann 1 (SW1). From time-series photometry we find that SW1 is continually active near perihelion ($R \sim 6$ AU), with an integrated magnitude ~ 13, and a mass loss rate in dust of order 10 kg s^{-1}. A simple model was formulated which is able to account for both the newly discovered persistent coma, and the more famous outbursts, in a natural way.

Results from a 2 year study of 2060 Chiron were analysed and published. The new time-series observations reveal impulsive brightening in Chiron at a rate 150 times greater than in the 2-year "outburst" noted by Hartmann *et al.* (1990). This observation suggests that Chiron is losing mass in a series of sporadic ejections, rather than in the smooth and continuous fashion implied by the 2-year event. We attribute the mass loss to surface materials with the volatility of CO or CO_2 ices.

Time series photometry is being collected on about 2 dozen other comets, including representatives from dynamically new and dynamically old groups.

c). In funding year 2, I plan to continue the program of time-series observations of comets. By its very nature, this is a long-term (multi-year) program, and the full significance of the science will become apparent only from a detailed analysis of the *total* data-set now being accumulated. I intend to continue to exploit the observational facilities on Mauna Kea for this project. My first year at IfA has convinced me that Mauna Kea is a truly remarkable site, and is ideally suited to the research planned under this NASA proposal.

d). **Bibliography**

J. X. Luu and D. C. Jewitt (1989), "On the Relative Numbers of C-Types and S-Types Among Near Earth Asteroids", *Astronomical Journal,* **98**, 1905 - 1911.

D. C. Jewitt (1990), "Continuous Activity in Comet P/Schwassmann Wachmann 1", in Asteroids, Comets Meteors III, eds. C. Lagerkvist, H. Rickman, B. Lindblad and M. Lindgren, University of Uppsala Press, Sweden, pp. 347 - 352.

J. X. Luu and D. C. Jewitt (1990), "CCD Spectra of Near-Earth and 3:1 Resonance Asteroids", in Asteroids, Comets Meteors III, eds. C. Lagerkvist, H. Rickman, B. Lindblad and M. Lindgren, University of Uppsala Press,Sweden, pp. 143 - 146.

D. C. Jewitt (1990), "The Persistent Coma of Comet P/Schwassmann Wachmann 1", *Astrophysical Journal,* **351**, 277-286.

J. X. Luu and D. C. Jewitt (1990), "CCD Spectra of Asteroids I. Near-Earth and 3:1 Resonance Asteroids, *Astronomical Journal,* June issue.

D. C. Jewitt (1990), "Cometary Photometry", invited review for Comets In The Post - Halley Era, eds. R. Newburn, M. Neugebauer and J. Rahe, Bamberg, Germany, April 24 - 28 1989. In Press.

D. C. Jewitt and J. X. Luu (1990), "The Submillimeter Radio Continuum of Comet Brorsen-Metcalf", *Astrophysical Journal,* submitted.

J. Luu and D. Jewitt (1990), "Cometary Activity in 2060 Chiron", *Astronomical Journal,* submitted.

Infrared Observations of Outer Planet Satellites

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T.V. Johnson

A. **OBJECTIVE:** This tasks supports IR observations of the outer planet satellites. These data provide vital information about the thermophysical properties of satellite surfaces, including internal heat sources for Io. Observations include both broad and narrow band measurements in the 2 to 20 μm spectral range. Most observations are carried out at the IRTF facility on Mauna Kea. Types of observation and target priority are determined to make maximum use of existing data from Voyager and other missions, support on-going and planned missions such as Galileo, and to develop techniques and data for planning new missions and instrumentation.

B. **PROGRESS:** The program in the last year has aimed at obtaining longitude coverage on Io to establish stability of hot spot patterns previously reported. In 1988, several runs produced the most complete data set for an apparition since we started the program in 1983; unfortunately bad weather limited coverage of key longitude ranges containing the largest known hot spot Loki. Among the preliminary results is the observation of an outburst in Io's thermal flux that was measured at 4.8, 8.7 and 20 μm. Analysis of those data has given the best evidence to date of silicate volcanism on Io; this is one of the most significant pieces of the puzzle as to the relative roles of silicate and sulfur volcanism on Io. We are collaborating with J. Goguen (JPL) in analysing mutual event data which have already improved ephermeris information for the satellites and placed significant limits on the characteristics of any leading side hot spots. Plans are underway for a major campaign to observe the next set of events.

C. **PROPOSED WORK:** During 1989, we plan a series of 3 to 4 observing sessions. Emphasis will be on further study of high temperature eruptive events on Io, on studying the suspected variability of the high temperature component(s) suggested by last year's data and on obtaining longitude coverage constraining the hot spots in the Loki region.

D. **SUMMARY BIBLIOGRAPHY:** Johnson, T.V. et al., Io: Evidence for silicate volcanism in 1986; Goguen, J.E. et al., Io hot spots: IR photometry of satellite occultations; Goguen, J.D. e al., Io hot spots: Satellite occultations of sources.

Goldstone Solar System Radar

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R.F. Jurgens

A. Objectives: (1) Planning, direction, experimental design, and coordination of data-acquisition and engineering activities in support of all Goldstone planetary radar astronomy. This work demands familiarity with the various components of a planetary radar telescope (transmitter, receiver, antenna, computer hardware and software) as well as knowledge of how the entire system must function as a cohesive unit to meet the particular scientific objectives at hand in a given observation. (2) Support radar data-processing facilities, currently being used for virtually all Goldstone data reduction: a VAX 11/780 computer system, an FPS 5210 array processor, terminals, tape drives, and image-display devices, as well as a large body of data-reduction software to accommodate the variety of data-acquisition formats and stratagems.

B. Progress: Since the completion of the 70m antenna upgrade in June, 1988, the GSSR has supported 93 tracks and acquired echoes from Mercury, Venus, Mars, Phobos, Ganymede, Callisto, Europa, Saturn's rings and asteroid 1980PA. Many of these observations were made using the new dual-polarization receiving system, the high resolution ranging system or the wide band digital spectrum analyzer at DSS-13. Four of the tracks used the Goldstone/VLA bistatic mode to make images of Saturn's rings and Mars. Most major objectives of all experiments were met. New data verification software has been developed for each acquisition system.

C. Proposed Work: (1) Oversee execution during 1989-90 of observations of various targets including Mercury, Venus, Galilean satellites, Titan, and two asteroids. (2) Modify data verification programs to include the formats for two new high through-put data acquisition programs. (3) Write hardware requirements for new DSS 12 and 13 stations to meet requirements of Support Instrumentation Requirements Document and Network Support Plan. (4) Plan hardwgare and software modifications for DSS 14 to implement more flexible data acquisition configurations. (5) Provide requirements documents for new programmed local oscillators. (6) Supervise calibration activities. (7) Manage the Radar Astronomy VAX.

D. 5 journal articles, 6 abstracts.

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Planetary Microwave and Submillimeter Astronomy

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Michael J. Klein

a. STRATEGY: Study solar system physics and meteorology of the planets, their satellites, and comets by measuring radio emission from microwave to submillimeter wavelengths. Objectives include: (1) spectroscopic and continuum observations with the new JPL and Caltech submillimeter receivers at the Caltech Submillimeter Observatory (CSO) on Mauna Kea; (2) continue to monitor the time variable planetary phenomena (e.g. Jupiter and Uranus) at centimeter wavelengths using the NASA antennas of the Deep Space Network (DSN); (3) continue to develop analytical software to plan the observing program and interpret the observational data.

b. ACCOMPLISHMENTS: In January 1990, we participated with an international group of astronomers (E. Lellouch, M. Belton, I. dePater, S. Gulkis, and T. Encrenaz) in a set of observations to search for SO_2 and H_2S in the atmosphere of Io using the IRAM 30-meter telescope in Spain. These observations resulted in the detection of SO_2 transition at 221.965 GHz (seen in emission with a temperature contrast of about 19 K at Io and ~600 KHz line width). This detection constitutes the first direct global observation of Io's neutral atmosphere.
We also published a paper (with Dr Paul Steffes, Georgia Tech) reporting precision measurements of the microwave continuum spectrum of Venus from 1.3 to 3.6 cm and deriving upper limits to the concentration of H_2SO_4 in the Venus atmosphere.
Collaborating with UC Berkeley, we are conducting a study of Jupiter's synchrotron emission to search for short term variations with timescales as short as a few days. Data are currently being calibrated and analyzed.

c. ANTICIPATED ACCOMPLISHMENTS: We plan to: (1) Continue our study of the sulfur chemistry of Venus via modeling and observations of the microwave spectrum, including new measurements at 22 and 32 GHz; (2) Publish our report on the short term variation study of Jupiter's radiation belts; (3) Begin system evaluation and calibration measurements of the 600 GHz (0.5mm) receiver at CSO as soon as it is installed on the telescope (currently scheduled to occur late in 1990); (4) Conduct several precision measurements of Uranus to update our long-term variability study of that planet's brightness temperature at 3.6 cm.

d. PUBLICATIONS:

Gulkis, S., P.D. Batelaan, M.A. Frerking, M.J. Klein, T.B.H. Kuiper, H.M. Pickett, M.M. Schaefer, P. Wannier, D. Bockelee-Morvan, J. Crovisier, P.J. Encrenaz, P Zimmermann, and J.L. Destombes, "Search for water in comet P/Halley at 380 GHz", Astron. & Astrophys. **213**, 465-468 (1989).

Russell, C.T., J.J. Caldwell, I. dePater, J. Goguen, M.J. Klein, B.L. Lutz, N.M. Schneider, W.M. Sinton, and R.A. West, "International Jupiter Watch: A program to study the time variability of the Jovian system", Adv. Space Res. **10**, No. 1, (1)239 - (1)242 (1990).

Steffes, P.G., M.J. Klein, and J. M. Jenkins, "Observations of the Microwave Emission of Venus from 1.3 to 3.6 cm", Icarus **84**, (in press, 1990).

Infrared Spectroscopy of Jupiter and Saturn

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Roger F. Knacke

a. Strategy: High resolution infrared spectroscopy provides unique insights into the chemistry and dynamics of the atmospheres of Jupiter and Saturn. The 5 μm spectral region, which is transparent to deep levels, is particularly useful for the identification of molecules that are present at very low (parts per billion) concentrations. These are tracers of convective and strongly non-equilibrium processes in the atmospheres. The observations support and complement *Voyager* and *Galileo* science, since for selected molecules, ground-based spectroscopy is more sensitive to very low mixing ratios, while spacecraft mass spectrometers probe molecules that are spectoscopically inaccessible from Earth.

b. Accomplishments: The search for arsine, AsH_3, that we proposed was successfully concluded with the discovery in Saturn and Jupiter. A prominent absorption feature in both planets near 4.7 μm coincides with the ν_3 Q branch of AsH_3, and a smaller absorption at the location of the ν_1 Q branch of AsH_3 is observed in Saturn. Arsenic is only the eighth element detected in the atmospheres of the giant planets. The mole fractions of AsH_3 are $qAsH_3 = 3 \pm 1$ ppb in Saturn and $qAsH_3 = 0.3 \pm 0.1$ ppb in Jupiter, and are probably representative of the As/H ratio in the gaseous envelopes. Arsenic is significantly enriched over the solar abundance in both planets, with AsH_3 about a factor of ten higher in Saturn. The enrichments are consistent with core instability models for the formation of the giant planets. Models of arsenic chemistry suggest that vertical convection inhibits depletion of AsH_3.

c. Anticipated Accomplishments: Recent laboratory data of PH_3 make possible much more precise synthetic spectral models, thus opening new opportunities for the investigation of giant planet atmospheres. We propose to observe 5 μm spectra of both Jupiter and Saturn to continue the search for new molecules. Observing time on the IRTF has been assigned for intermediate resolution observations of Titan in the 5 μm spectral region. The project will focus on resolving the controversies surrounding CO on Titan.

d. Publications

Noll, K.S., Geballe, T.R., and Knacke, R.F. 1989, "Arsine in Saturn and Jupiter," Ap. J. (Letters), 338, L71.

Noll, K.S., Knacke, R.F., Geballe, T.R., and Tokunaga, A.T., 1988, "Evidence for Germane in Saturn," Icarus, 75, 409.

Advanced Infrared Astronomy

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a. **Strategy:** This task supports the application of infrared heterodyne and Fourier transform spectroscopy as well as infrared arrays to ultra-high resolution studies of molecular constituents of planetary atmospheres. High spectral and spatial resolution measurement and analysis of individual spectral lines permits the retrieval of atmospheric molecular abundances and temperatures and thus, information on local photochemical processes. Determination of absolute line positions to better than 10^{-8} permits direct measurement of gas velocities to a few m/sec. Observations are made from ground based observatories (NSO McMath solar telescope at Kitt Peak and the NASA Infrared Telescope Facility on Mauna Kea, Hawaii).

b. **Accomplishments:** We incorporated our Venusian wind measurements in the lower thermosphere with results from CO microwave measurements, Pioneer Venus thermospheric sounding, dynamical models, and early heterodyne results on the mesosphere into a comprehensive self consistent picture of Venusian circulation. The need for mesospheric return flow was determined and measurements to confirm this return flow were made using $^{13}CO_2$ absorption features from the mesosphere of Venus. The data is being analyzed. Infrared heterodyne observations of C_2H_6 on Neptune were made. Mole fractions ~3×10^{-6} were retrieved near the 0.3 mbar level. Existing photochemical models for hydrocarbons on Neptune were tested. Our results indicate that either eddy mixing must be significantly lower in the lower stratosphere or the temperature must be warmer by ~15 K in the 2 - 0.2 mbar region. Spatial distribution of C_2H_4 and C_2H_6 on Jupiter were measured and the behavior of hydrocarbons near Jovian polar regions studied. Ethylene line emission from the north polar hot spot was detected for the first time from the ground and a greater than 10-fold enhancement was observed. Ethane emission was found to be greatly enhanced over a a large area in the north polar region as compared to the south polar region. This result is different from observations in 1982-1983. These data are being analyzed and interpreted in terms of changes in temperature, photochemistry and stratospheric dynamics. We continued the study of non-acoustic thermal wave structure on Jupiter, which was observed in the 7-13μm band (both at 20°N and the equator). Similar wave structure was found in 7.8 μm stratospheric methane emission, with approximately the same phase and twice the temperature amplitude, as in the tropospheric 7-13 μm broadband emission.Further observations and data analysis are continuing.

c. **Anticipated accomplishments:** We propose to study the temporal variability and morphology of the stratospheric emission from the principal hydrocarbon constituents (CH_4, C_2H_2, C_2H_6) from Jupiter's polar regions. The focus will be to image the polar hot spots and auroral regions and determine any correlation with ultraviolet auroral activity as observed simultaneously with the IUE. The goal is to investigate the energy source for the IR enhancement (e.g. energetic particles) and resultant species distribution around the north polar hot spot, which would be dependent on the changes in local photochemistry and diffusion of the product hydrocarbons in the Jovian stratosphere. The study of Jovian planetary thermal waves will continue in the three hydrocarbons and in the region of hydrogen opacity near 20μm. Observations of global circulation on Mars using the 10 μm CO_2 spectra will continue. Ethane abundances on Saturn and Titan will be determined using line spectra measurements. An attempt to measure Titan's global circulation will also be made using the measured C_2H_6 lines.

d. Publications:

1989 " Is ethane varying in the Jovian north polar "hot spot" ?", T. Kostiuk, F. Espenak, and M. J. Mumma, in Time Variable Phenomena in the Jovian System, NASA Conf. Pub. (ed. M. Belton , R. A. West, and J. Rahe) NASA SP-494.

1989 "Infrared studies of hydrocarbons on Jupiter", T. Kostiuk, F. Espenak, M. J. Mumma and P. Romani, Infrared Physic **29**,199.

1989 "A search for P-mode oscillations of Jupiter: Serendipitous observations of non-acoustic thermal wave structure", D. Deming, M. J. Mumma, F. Espenak, D. E. Jennings, T. Kostiuk, G. Wiedemann, R. Lowenstein, and J. Piscitelli, Astrophys. J. **343**, 456.

1989 "Probing our solar system at infrared wavelengths", M. J. Mumma, Infrared Physics **29**, 167.

1989 "Absolute wind measurements in the lower thermosphere of Venus using infrared heterodyne spectroscopy", J. Goldstein Ph. D. Thesis. Also- NASA Contractor Report CR-4289 (1990).

1990 "Ethane abundance on Neptune", T. Kostiuk, F. Espenak, P. Romani, D. Zipoy, and J. Goldstein, Icarus, submitted.

Cometary Spectroscopy and Imaging

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a. Strategy: This is an continuing observational program to investigate the spectroscopic and morphological characteristics of comets and selected minor planets over a wide range of heliocentric distances as they may suggest or constrain models of cometary processes, their formation environments and evolution. Direct images of all observable comets (M2<21) and 300-800nm spectra of the brighter ones are obtained (weather permitting) on a monthly basis with a novel CCD spectrograph/camera. The direct images may be are used for astrometry, photometry and studies coma and tail morphology. In some cases, dust coma anisotropy which can provide information on the spin vector and gross surface morphology. When the comet is bright enough, spectra may provide identification and scale lengths of the principal emissions from which the abundance of gas, dust and ions in different comets can be compared. Long exposures of minor planets in nearby and comet-like orbits are made to search for faint comae.

b. Accomplishments: Direct CCD images (and sometimes spectra) were obtained of Comets Austin (1989c1; IAUC 4973), Brorsen-Metcalf(1989o), Clark (1989h), duToit-Neujmin-Delporte (1989l), Gehrels 2 (1989n), Gunn, Halley (1986III), Helin (1989s), Helin-Roman-Alu (1989v), Helin-Roman-Alu 1 (1989w), Helin-Roman-Alu 2 (1989y), Helin-Roman-Crockett (1989b), Kearns-Kwee (1989u), Kopff (1988k), Lovas (1989p), McKenzie-Russell (1989f1), Okazaki-Levy-Rudenko (1989r), Parker-Hartley (1989i), Pons-Winnecke (1989g), Russell 3 (1989d), Russell 4 (1989g1), Schwassmann-Wachmann 1, Skochenko (1989e1), Schwassmann-Wachmann 3 (1989d1), Shoemaker (1989e), Shoemaker (1989f), Shoemaker-Holt (1989j), Tuttle-Giacobini-Kresak (1989b1), VanBiesbroeck (1989h1), West-Hartley (1989k), Wild 2 (1989t), Wild 3 (1990a; IAUC 4954), Wilson (1987VII), and Yanaka (1989a). Comets Brorsen-Metcalf and Okazaki-Levy-Rudenko had unusually high gas/dust ratios and highly visible H_2O^+ ion tail features. Continuous sequences of images in the 619nm (0,8,0) H_2O^+ band showed the formation of folding rays from diffuse hoods 17,000km sunward from the nucleus to a narrow central tail core starting within 600km of the nucleus. Spectra of three hours effective integration on 3060 Chiron failed to show any spectral emissions from its faint coma. Spectra of the mission targets asteroids 66 Maja and 951 Gaspera were obtained, and deep coronagraphic images of the earth-approaching asteroid 1989 PB showed no evidence of a coma when 0.03 AU from the Earth. Astrometry (reduction by S. Bus of Lowell Obs.) of the fast-moving asteroid 1989 WM was obtained shortly after discovery.

c. Anticipated accomplishments: Monthly CCD imaging, spectral, and astrometric observations of comets and asteroids will continue with emphasis on mission target objects. Coordinated observations of Comet Austin are planned to obtain simultaneous spectra over the 300-2500nm range. Analysis of the ion tail kinematics of Comets Brorsen-Metcalf and Okazaki-Levy-Rudenko will be completed.

Publications:

Larson, S.M. (1990). Dust jet morphology in 1986 ground-based images of Comet Halley. In Comet Halley 1986: Worldwide Investigations, Results and Interpretations, Ellis Horwood Library of Space, Series in Astronomy, in press.

Larson, S.M., Edberg, S.J. and Levy, D.H. (1990) The modern role of visual observations of comets. Comets in the Post-Halley Era, ed. R.L. Newburn, Kluwer Academic Pub., in press.

Mid-Infrared Spectroscopy of the Moon and Mars

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a. This investigation is intended to obtain spectra in the region of thermal emission (7-14mm) of the surfaces of the Moon and Mars. This wavelength region contains the fundamental stretching absorption of the the Si-O bond and so contains fundamental information about the silicate mineralogy of these surfaces. Spectral features observed in emission can be used to determine the silicate mineralogy of the surface. The surface of Mars is expected to be largely basaltic, especially in the volcanic terrains, but the abundance of silicic or ultramafic lavas is unknown. The ancient cratered terrain could have a variety of compositions none of which are well constrained by the current data set. In the case of the Moon, spectroscopy in the near-infrared has shown that areas far from the Apollo and Luna landing sites has quite unusual compositions. Spectroscopy in the mid-infrared is well suited to determining lunar compositions, particularly for rock types containing iron-free minerals to which the near-IR is insensitive. This portion of the study is intended to make measurements of areas which are suspected to be either silicic or ultramafic terrains to confirm or deny these compositional hypotheses.

b. Several observing run have resulted in considerable data on both the Moon and Mars. Unfortunately, during the course of this investigation it was discovered that the Si:As photoconductor spectrophotometer used for most of these measurements suffered from nonlinearity which was greatly exacerbated by the great difference in flux between the bright planetary objects and the standard stars. One lunar observing run with a bolometer detector proved much more successful and showed spectral differences from location to location on the Moon consistent with previous measurements. I also discovered that observing areas near the lunar limb (forced by IRTF chopping secondary constraints) reduces the spectral contrast relative to earlier measurements.

c. This year will be devoted to observing several areas on Mars and the Moon with the bolometer spectrophotometer and the Faint Object Grating Spectrograph operated by Fred Witteborne at Ames Research Center. Lunar progress is intended to result in definitive measurements of the silica content of lunar terrains suspected to be ultramafic (derived from the lunar mantle) or silicic (derived from highly evolved lunar magmatism. Mars results will include 1) observing the surface composition if the atmosphere is relatively clear, or 2) constraining the silica content of the dust in the atmosphere and comparing these results to Viking Lander and Mariner dust composition measurements.

d. Two abstracts, two presentations.

Photometric and Polarimetric Imaging of the Giant Planets In Narrow Spectral Bands

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a) Strategy. The research grant supports the recording of new, synoptic, high signal-to-noise, spectrally resolved, photometric and polarimetric CCD images of Jupiter in narrow spectral bands. The photopolarimetric observations are designed to characterize the vertical structure of the Jovian atmosphere, and put constraints on the nature and distribution of the aerosols in it through detailed study of the photometric and polarizing properties of belts and zones in methane absorptions and in continuum bandpasses. We expect to continue the coverage for a time period sufficient to look for and study long-term temporal variations in it. These images will form a homogeneous set of ground-based data, including observations contemporaneous with the *Galileo* mission which are required for the interpretation of the spacecraft data. They also provide the link that serves to tie the "snapshot" of Jupiter obtained during the encounter to more temporally extended studies of the long-term variations of the atmosphere, and they establish a database for fundamental research on this giant planet.

b) Accomplishments in 1989 Funding for this proposal began in January 1989, and since then we have recorded photometric and polarimetric images of Jupiter in three methane bands and one ammonia band and in three continuum bandpasses at several phase angles near 11°, 8°, and 3°. We have reduced and calibrated most of the images obtained at 11°and 8°phases, and we completed the reductions and calibrations for those data obtained for the 1986, 1987, and 1988 appparitions which encompass phase angle near 6°and 0°, but at times when Jupiter's atmosphere had a visual appearance strikingly different from those observed in 1989. We have developed the algorithms for extracting from these photomteric intensity images for derivations of the vertical structure of the Jovian atmosphere and polarimetric maps to study the dust and haze component. We have begun analyzing whole, integrated disk polarizations to quantify the the polarimetric changes that have occurred with the recent dramatic changes in Jupiter's visual appearance. Our photometric intensity images will also be used to quantify the changes in vertical structure that have accompanied the visual changes.

c) Anticipated Accomplishments in 1990. During 1990 we expect to continue to obtain narrowband photometrically calibrated images of Jupiter to extend our polarimetric data set to include a broader range of phase angles and more complete global coverage. his coverage will follow the temporal variations that are occurring in the atmosphere. We also expect to begin developing the model anlaysis techniques that will be applied to these data to extract Jupiter's vertical atmospheric structure and polarizing hazes, and we will be attempting to analyze and interpret the whole, integrated disk polarization meeasures and their changes since 1986.

d) Papers Published, In Press or Submitted in 1989.

"Spatial and Temporal Variations in the Atmosphere of Jupiter: Polarimetric and Photometric Constraints" (B. E. Carlson and B. L. Lutz), in *Proceedings of the International Workshop on Time-Variable Phenomena in the Jovian System* (M. J. Belton and R. A. West, eds.). NASA SP–494, pp. 289–296 (1989).

"International Jupiter Watch; A Program to Study the Time Variability of the Jovian System" (C. T. Russell, J. J. Caldwell, I. de Pater, J. Gougen, M. J. Klein, B. L. Lutz, N. M. Schneider, W. M. Sinton, and R. A. West), *Adv. in Space Sci Res.* **10**, 239–242 (1990).

Outer Planet Studies

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a) Strategy. The research supported by this grant focuses on observational studies of the composition, structure and variability of planetary, satellite and cometary atmospheres, and the investigation of the problems associated with the fundamental calibration of these data. The techniques used include spectroscopy, spectrophotometry and photometric imaging in the spectral region from 3000 Åto 5 μ-m. In addition to carrying out basic research into the origin, evolution and current state of the solar system, these studies provide "ground-truth" support for observations of the solar system by NASA's missions, including the *Voyager* and *Galileo* spacecraft, the *Hubble Space Telescope*, and the proposed *CRAF–Cassini* mission.

b) Accomplishments in 1989. Major accomplishments during the past year include: (1) Completion and acceptance for publication in *The Astrophysical Journal* of our study of CH_3D in the spectrum of Neptune and a determination of the mixing ratio in its atmosphere; (2) Completion and acceptance for publication in *Icarus* of our study of the aboriginal deuterium enrichment in protosolar ices and their relationship to the interstellar medium; (3) Successful recording of the spectrum of HDO and H_2O in the atmosphere of Venus and a preliminary analysis of it which indicates that D/H on Venus is 50 to 100 times that measured on Earth; (5) Successful recording of the spectra of Triton and Pluto in a study of its contribution of methane to its atmosphere and icy surface; (6) Continuation of our long-base line time series of spatially-resolved, spectrophotometric observations of the belts and zones of Jupiter; (7) Completion of a time series of spectrophotometric observations of Neptune carried out contemporaneous with the *Voyager* encounter with it.

c) Anticipated Accomplishments in 1990. Major efforts proposed for the next year include: (1) Completion of the analysis of the spectrum of Venus and the determination if the abundance HDO in the atmosphere of Venus and its implied D/H ratio, as part of our investigation of the distribution of deuterium in the solar system and its relationship to the origin and evolution of the planets; (2) Completion of our study of non-equilibrium CO emission in the infrared spectrum of Venus, accidentally discovered in our quest for deuterium compounds; (3) Recording of new spectra of Triton and Pluto to study the temporal variations of CH_4 in its spectrum and the analysis of our 1989 observations; (4) Publication of our time series of spectrophotometric observations of Neptune and a determination of its geometric and Bond albedos as part of our study of temporal variability of its atmosphere and our support of the 1989 *Voyager* encounter; (5) Publication of the recalibration of the Sun against Vega and continuation of our study of the fundamental calibration problems associated with solar analogs, needed to accurately determine planetary albedos on a common photometric scale; (6) Continuation of our time series of spatially resolved spectrophotometric observations of the Jovian belts and zones to characterize the spatial and temporal variations of the Jovian atmospheric structure in support of the *Galileo* mission; (7) Recording of new spectrophotometric and spectroscopic observations of selected, target-of-opportunity comets in support of the cometary program goals of the *CRAF–Cassini* mission.

d) Papers Published, In Press or Submitted in 1989.

"Spatial and Temporal Variations in the Atmosphere of Jupiter: Polarimetric and Photometric Constraints" (B. E. Carlson and B. L. Lutz), in *Proceedings of the International Workshop on Time-Variable Phenomena in the Jovian System* (M. J. Belton and R. A. West, eds.). NASA SP-494, 289–296 (1989)

"Jupiter" (with C. A. Gullixson). *IAU Circ* No 4810 (1989).

"Measurements of the D/H Ratio in Planetary Atmospheres by Ground-Based Infrared Spectroscopy" (C. de Bergh, B. L. Lutz, T. Owen and J. P. Maillard). ESA SP–290, 41–47 (1989).

"International Jupiter Watch; A Program to Study the Time Variability of the Jovian System" (C. T. Russell, J. J. Caldwell, I. de Pater, J. Gougen M. J. Klein, B. L. Lutz, N. M. Schneider, W. M. Sinton, and R. A. West). *Adv. in Space Sci. Res.* **10**, 239–242 (1990).

"Monodeuterated Methane in the Outer Solar System. IV. Its Detection and Abundance on Neptune" (C. de Bergh, B. L. Lutz, T. Owen, and J.–P. Maillard). *Astrophys. J.*, in press (June 10, 1990) .

"Deuterium Enrichment in the Primitive Ices of the Protosolar Nebula" (with T. Owen and C. de Bergh). *Icarus*, in press.

Astrometric Observations of Comets and Asteroids and Subsequent Orbital Investigations

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(a) Astrometric observations are made with the 1.5-m reflector at the Oak Ridge Observatory.
(b) The most important occurrence during the past year has been the long-awaited transition from photographic to CCD observations. Once Ford-Aerospace 2048 x 2048 chips became available this was actually accomplished quite quickly and smoothly, without any interruption in the observing program. After some experimentation with a borrowed CCD in 1989 August and September, the final photographic plate to be taken with the 1.5-m reflector was exposed on September 27. The use of the CCD is allowing the total number of observations made to be increased by an order of magnitude. During the autumn the CCD observations were reduced much as the photographic observations had been done, using the Astrographic Catalogue, and some backlog quickly developed. During the winter a very concise version of the new STScI Guide Star Catalogue (separated into many files but using only five bytes to give positions and magnitudes for each of some 12 million stars) was constructed on the disk of a MicroVAX GPX computer, and this has greatly improved the efficiency of the reduction process. Reference stars in the vicinity of the predicted position of a minor planet or comet are selected in less than one second, and an image can be displayed on the screen and an automatic measurement and complete astrometric reduction performed in about five minutes. Although the positions have not yet been published, this has now allowed the autumn backlog to be eliminated. Observations of one new comet and the returning P/Brorsen-Metcalf (the prediction for the latter proving to be considerably in error) were made within a day of discovery/recovery, and for two of the comets our observations were the final ones to be obtained anywhere. 1989 was a record year for discoveries of new Apollo objects and other earth-approachers, and of these we observed 1989 FB, FC, JA, OB, RS1 and WM. Several observations were made of (243) Ida and (951) Gaspra, objects of interest in connection with the Galileo mission.
(c) Further observational efficiency (but only by a factor of 2) should be possible with the use of a second CCD as an autoguider. Consideration will also be given to the possibility of offsetting for the motion of the target object.
(d) Observations published in 32 Minor Planet Circulars and 5 IAU Circulars. Orbits in same publications and new editions of the orbit catalogues.

Asteroid Research

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A. **OBJECTIVES**: The purpose of this task is to carry out asteroid research in support of NASA's planetary exploration objectives. Original research is carried out on asteroids in order to better characterize asteroids as a whole and measure the properties of individual objects. This information is needed for the planning and design of NASA asteroid flyby and rendezvous missions (e.g. Galileo, CRAF, Cassini).

B. **PROGRESS**: [1] Our long ongoing work on asteroid taxonomy has been published. The philosophy behind our three-parameter asteroid taxonomy was to create a relatively simple system, using a minimal number of parameters, sufficient to meet the needs of selecting asteroids for spacecraft flyby. The three parameters we settled upon were IRAS albedo, U-V and v-x color indices. Our classification algorithm explicitly accounts for the observational uncertainties in each of the classification parameters, a feature not found in other classifications. Thus, the derived classification in our system depends upon both the parameter values and their uncertainties. Using high quality data we find 11 taxonomic classes. [2] Work on the measurement of asteroidal diameters and albedos continued with the photometry for 22 Aten, Apollo and Amor asteroids presently in press in the Astronomical Journal. [3] We supported the Asteroids II book (U. of AZ Press) by preparing three chapters describing the Asteroid and Comet Survey with the Infrared Astronomical Satellite (IRAS), its results and some of the interpretation of the data. These papers are presently in press. [4] Funding under this task supported Matson's activities as a member of the NASA Planetary Astronomy MOWG and the IRTF MOWG.

C. **PROPOSED WORK**: [1] We will continue to give top priority to any near-Earth asteroids which become available for observation. [2] Radiometry for several dozen asteroids will be reduced and submitted for publication. [3] The taxonomic work will be extended to fainter asteroids. [4] This task will continue to support Matson's involvement in NASA MOWG's.

D. **SUMMARY BIBLIOGRAPHY**: Tedesco, E. F., et al., A Three-Parameter Asteroid Taxonomy, Astron. J. 97, 580-606 (1989). Veeder, G. J., et al., Radiometry of Near-Earth Asteroids, Astron. J. 97, 1211-1219. Three papers in press.

The Radial Velocity Search for Extrasolar Planets

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__a. Strategy:__ We are in the midst of a long-term program of radial velocity measurements to search for planets orbiting stars other than the Sun. No doubt the first confirmed discovery of an extrasolar planet will be of great scientific and popular interest, but the long-range goal is to learn the systematics of planetary systems. Such empirical data are needed vitally to advance understanding of the formation of our own solar system as well as solar systems in general.

The reflex acceleration induced on stars by planets can be sensed by measuring the small, slow changes in the line-of-sight velocities or the angular positions of stars. Whether there is more than one planet orbiting a star is an important qualitative distinction that will aid taxonomy of planetary systems. Combination of radial velocity and astrometric data on the same stars may permit such a determination because radial velocity measurements are more sensitive to planets in small orbits, while astrometry preferentially detects planets in large orbits.

__b. Accomplishments:__ To detect planetary perturbations, each data series must be made on a uniform instrumental scale for as long as it takes a planet to orbit its star. We have a spectrometer of extreme stability and unprecedented sensitivity to changes in stellar radial velocities. We began observing with a temporary setup in 1985. After an extensive campaign of improvements to the hardware, we "froze" the configuration of this instrument in December 1986 and began our long-term series of uniformly calibrated observations. Between 1987 January and 1990 March (inclusive) we have made 1324 observations of 16 near-solar type stars on 314 nights.

Our data show our instrument has the stability necessary to detect the reflex acceleration induced by a Jupiter-mass planet on a solar type star, if the orbit has a period less than 12 years and a favorable inclination to the line of sight. To verify the noise floor (lower limit of long-term systematic errors) of our instrument, we have been observing the solar spectrum reflected off a lunar crater. In three years, 299 such observations show that our instrument has a noise floor of ± 10 m/s (McMillan et al. 1990, Proc. SPIE 1235, in press).

In addition to our efforts to detect planets orbiting solar-type stars, we are seeing slow velocity variations in some K giants which are probably due to pulsations.

__c. Plans:__ Our data show small velocity perturbations in some solar-type stars which should become clearer after additional years of observing. We propose to continue the observing program through at least 1993.

Observations Evidence of Aging Process in Comets

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a) Strategy

The main emphasis of my NASA research is to search for systematic differences among two groups of comets: periodic comets which spend most of their time in the vicinity of the inner Solar System and new comets which are believed to be passing through the inner Solar System for the first time. In order to understand the internal structure and primordial composition of comets, both important physical clues to the early Solar System, evolutionary or aging processes must be first investigated. There are many theoretical reasons why aging or physical differences between orbital classes are expected. For example, as a comet is heated on its first close solar passage there are many irreversible chemical and physical changes which it may undergo, such as ice phase changes, loss of highly volatile ices, build up of a dust mantle from selective loss of volatiles when close to the sun and possible splitting due to thermal stresses. Understanding of physical and compositional differences will ultimately lead to a better understanding of cometary formation conditions in the early Solar System because the most pristine cometary material is probably a little altered remnant of this era.

Comets represent a very heterogeneous group of objects, therefore in order to gain an understanding of them as a group involves systematic observations of a statistically significant sample. Without spacecraft missions to comets, a detailed compositional analysis is not possible, instead, compositional information is usually obtained from ground-based spectroscopic observation of resonance fluorescence emission from the gas. Unfortunately, typical cometary emission species are usually seen only within a few AU of the sun and most appear at nearly the same heliocentric distance indicating that they are released when the cometary water ice sublimates and probably represent minor constituents bound as water ice clathrates. This technique, therefore, does not indicate the bulk composition of the comet. The present program circumvents some of these difficulties by studying the long term activity as a function of distance. The activity is judged on the basis of the shape of the brightness curve as a function of distance compared with that expected of an inactive body (such as an asteroid). Modelling is used to compare the total observed brightness with that predicted by sublimation models for various cosmochemically important ices (e.g. CO, CO_2, H_2O etc.). As a volatile begins to sublimate it will entrain dust particles from the surface in the gas flow and the effective scattering cross section of the nucleus will increase, making the comet appear much brighter than would an inert body. This is an effective way to detect activity even when the comet is so distant that no coma is resolvable.

b) Progress and Accomplishments

During the past year, there have been 10 successful observing runs (CCD imaging) using the University of Hawaii (UH) 2.2m, Canada-France-Hawaii (CFHT) 3.8m, Kitt Peak (KPNO) 4m, Cerro Tololo Interamerican Observatory (CTIO) 1.5m and schmidt (for the large southern declination targets) and the Univrsity of Arizona (UA) 1.5m telescopes. The cometary data base includes approximately 50 comets, representing a roughly even mixture of periodic and dynamically new (Oort) comets. With the exception of P/Halley, which exhibited activity until near 12.2 AU, all of the periodic comets appear inactive within 6 AU of the sun, whereas all of the Oort comets appear active (as judged by the brightness curve versus heliocentric distance and the existence of comae) at very large heliocentric distances (6-15AU) Water ice models for a comet on the pre-perihelion portion of its orbit have shown that the largest distance at which the equilibrium temperatures are warm enough for water ice sublimation is near 6 AU. In the case of P/Halley outbound, however, it may be that there is a lag in the propagation of heat into the low thermal conductivity nucleus, thus prolonging the activity out to larger distances.

The accompanying figure shows brightness within the central 5 arcsec radius as a function of heliocentric distance. This data clearly indicates that there is a systematic difference between the brightness of the dynamically new comets (plotted as "x") and the periodic comets (plotted as "+") as a function of distance. P/Halley is plotted as a filled circle inbound and open circle outbound. The data point near 20 AU represents a probable observation of the dynamically new comet Bowell. Although the field was only observed on one night and will need confirmation, an upper limit on the comet brightness may be placed which suggests that it has faded to its nuclear brightness and that activity must have ceased somewhere between 14 and 20 AU.

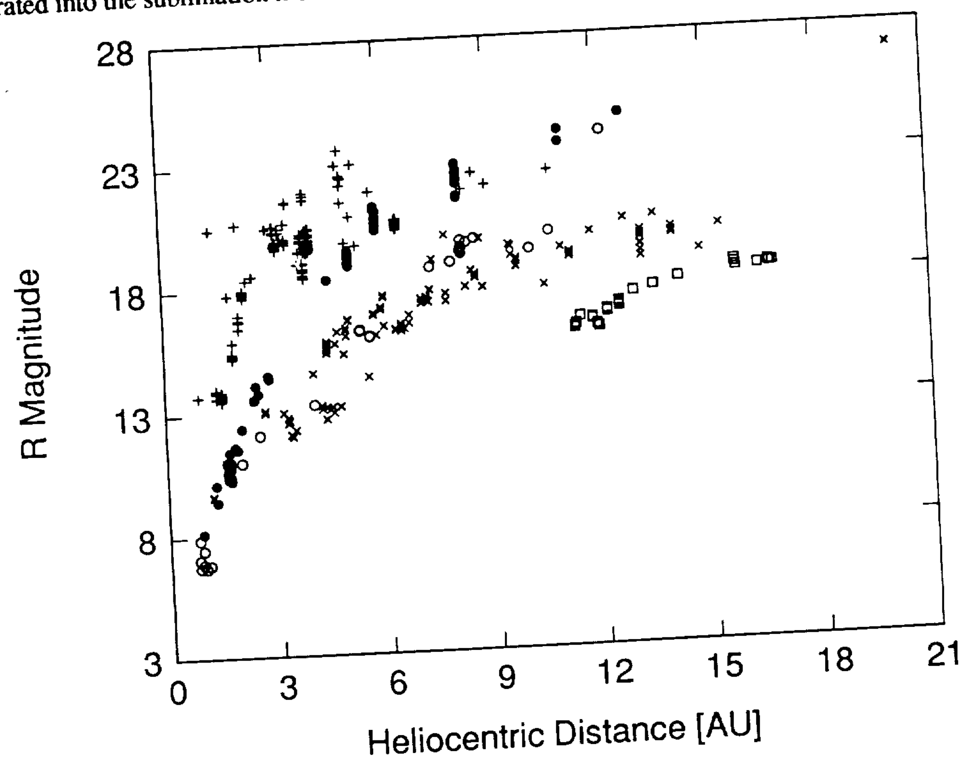
The boxes in the figure represent data for the unusual outer Solar System object, 2060 Chiron, which until recently was classified as an asteroid. However, broadband photometry since mid 1987 had indicated that Chiron was brightening much faster than expected for an inactive asteroidal body and some sort of cometary activity was suspected. The activity was confirmed when observations with the KPNO 4m telescope revealed the presence of a low surface brightness coma (Meech and Belton, (1989) *IAU Circular No. 4770*). Preliminary modelling of Chiron suggests that at 17.5 and 13 AU, when Chiron was observed to brighten, H_2O sublimation cannot be responsible. The most likely volatile active at these distances is CO. Not only is Chiron unique in the distance at which the initiation of cometary activity was observed, but given its large nuclear size (180 km diameter at the 2 sigma level) the coma has not been developing in a manner typical for most comets. Instead, it is being trapped in an atmosphere. The observed coma represents the small (sub-micron) particles that have achieved escape velocity. The Chiron coma work has been pursued in collaboration with Mike Belton. In an attempt to directly detect the volatile responsible for Chiron's activity, high resolution spectroscopic observations of Chiron have been made with the UH 2.2m and UA 1.5m telescopes in collaboration with Marc Buie. The spectra cover both the blue and red wavelength regions. No emission lines were immediately apparent at the telescope, however, reductions are in progress.

As mentioned previously, one of Chiron's unique aspects is its unusual size. Unfortunately, the size is not well constrained from the thermal measurements since Chiron was detected only at the 2 sigma level. The size, however, plays a critical role in the extent and shape of the atmosphere and coma. In collaboration with John Spencer, a 3 sigma detection at 20 microns has been made using the United Kingdom Infra-Red 3.8m telescope (UKIRT) in an attempt to improve the size estimate. Observations were hindered by poor weather, thus further thermal observations are planned for the fall.

c) <u>To Be Accomplished This Year</u>

The present data shows that statistically there is a clear difference between comet classes and that this is a function of the distances at which the comet is active. Determining the identity of the sublimating ice, however, requires observation of the point at which activity begins or ends (i.e. a function of the latent heat of sublimation of the ice). Therefore, in order to understand the composition of the comets, which may be different between the two comet classes, the comets must be followed to the maximum extent of their orbits. Without additional information, the expected brightness cannot be modelled uniquely because of uncertainties in the scattering cross sections of the grains, the grain masses, the nucleus size and rotation rate, etc. Some information on the grains is available from the color and coma morphology which is constrained by the radiation pressure-grain interaction. More direct observations of the grain properties are planned for this fall in collaboration with Martha Hanner, when near simultaneous thermal IR and visible photometry will be obtained for bright comets beyond 2 AU from the sun. This will provide information on both grain albedos and sizes. All of the dynamically new comets will continue to be observed until they are too faint to be detected, which may be on the order of 2-3 years from now for ground-based observation (i.e. approximately 26-27 mag). Plans are underway to apply for time on the Hubble Space Telescope for the faintest objects. The periodic comets will be followed throughout their entire orbits if possible, and deep images at large distances should reveal whether there is any evidence for activity beyond 6 AU. If not observed throughout the orbit (to aphelion), every effort will be made for early recovery of the comets. During the past couple years, 4 comets have been recovered in this program, two of which (P/Grigg-Skjellerup and P/Wild 2) were recovered near aphelion.

In addition to continuing to observe the comets, improvements to the simple thermal sublimation model are beginning. Due to the large number of free parameters, the present model is kept very simple since the main goal has been to ascertain which volatiles can supply dust to observed comae at particular heliocentric distances. Detailed radiation pressure analysis of coma morphology and in some cases dust tail structure will provide information on particle sizes within the coma. Instead of the present monodisperse particle sizes now in the thermal model, a particle distribution will be included. To date, there has been little emphasis on the heat transport into the nucleus. However, it is known that the observed behavior of a comet can be dominated by this heat transport, and this should not be neglected. The heat transport can be understood in terms of the large scale structure of the nucleus (such as shape and inhomogeneity) as well as on the thermal properties of the fine structure, porous, icy materials that compose the nucleus. For example, the thermal conductivity of non-porous water ice is a strong function of temperature, whereas calculations show that at low temperatures, the pore space will impede the flow of heat into the material, thus lowering the effective conductivity. Similarly, at high temperatures, water vapor in the pore spaces can greatly enhance the effective thermal conductivity. The addition of dust (silicates) to the nuclear ice will lessen the temperature dependence on conductivity in the case of water ice. In collaboration with Jackie Green (who is partially supported by this grant), the small and large scale thermal properties of the nucleus will be incorporated into the sublimation models and compared to observations.



Bibliography - Past year - Karen J. Meech

Green, D. W. E., H. Rickman, A. C. Porter and K. J. Meech (1990). "The Strange Periodic Comet Machholz", *Science* **247**, 1063-1067.

Hartmann, W., D. J. Tholen, K. J. Meech and D. P. Cruikshank (1990). "2060 Chiron: Colorimetry and Possible Cometary Behavior", *Icarus* **83**, 1-15.

Meech, K. J. (1990). "Aging in Comets", Invited review presented at IAU Colloquium 116 "Comets in the Post-Halley Era", Bamberg, chapter in *Comets in the Post-Halley Era*, submitted.

Meech, K. J. and M. J. S. Belton (1990). "The Atmosphere of 2060 Chiron". *Astron. J.*, submitted.

Occultation Studies of the Solar System

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a. Strategy. Occultations of stars by planets, satellites, planetary ring systems, and asteroids, provide valuable opportunities to probe the Solar System in ways that are otherwise impossible from the surface of the Earth. For example, one can precisely measure the size and shape of objects which are much too small to be resolved directly, accurately map the structure and transparency of ring systems, and detect the faintest trace of an atmosphere by observing these elusive events. In this investigation, we identify upcoming occultations through wide-ranging computer searches, provide accurate predictions for the more important events, and observe selected occultations with our specially designed portable photometric equipment.

b. Accomplishments. During the past year, we produced detailed predictions for the 3 July 1989 occultation of 28 Sgr by Saturn's satellite, Titan. A stellar occultation involving Titan had not previously been recorded, but as a result of these predictions, this event was widely observed and valuable results concerning Titan's atmosphere obtained. We also successfully observed the 19 August 1989 occultation of SAO 185928 by Vesta from two sites in Ecuador using compact CCD systems and portable telescopes. Those observations, combined with measurements from one other site, indicate that the diameter of Vesta is 561 ± 3 km, assuming the body is spherical. We have made substantial progress in the analysis of observations of the 9 June 1988 occultation of P8 by Pluto. A method has been devised whereby both a haze model and a thermal gradient model can be fitted to the observations from eight sites. The results, which are nearly ready for publication, indicate that the radius of the visible surface of Pluto may be significantly larger than previously believed. Predictions of 179 occultations by asteroids, planets, and certain outer planet satellites were computed and published for the years 1990 and 1991.

c. Expected Accomplishments. In the next year, a paper discussing Pluto's atmosphere based on the total data set from the recent Pluto occultation will be published. A companion paper dealing with the mass ratio of Pluto and Charon as derived from our extensive astrometry of the system is also planned, and the results of the 1989 Vesta occultation will be published. A major effort will be made to provide refined predictions for the 1 August 1990 occultation of SAO 187435 by Triton. Observations of the event will be attempted, if feasible. We also plan observations of excellent occultations by Vesta and Kleopatra. In both instances the primary objective will be specification of the precise shapes of these asteroids.

SUMMARY BIBLIOGRAPHY

Elliot, J. L., Dunham, E. W., Bosh, A. S., Slivan, S. M., Young, L. A., Wasserman, L. H., and Millis, R. L. (1989). Pluto's Atmosphere. *Icarus* **77**, 148–170.

Hubbard, W. B., Hunten, D. M., Reitsema, H. J., Brosch, N., Nevo, Y., Carreira, E., Rossi, F., and Wasserman, L. H. (1990). Results for Titan's Atmosphere and Its Occultation of 28 Sagittarii. *Nature* **343**, 353.

Millis, R. L., and Dunham, D. W. (1989). Precise Measurement of Asteroid Sizes and Shapes from Occultations. In *Asteroids II* (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), pp. 148–170. The University of Arizona Press, Tucson.

Millis, R. L., Wasserman, L. H., Bowell, E., Harris, A. W., Young, J. W., Barucci, M. A., Williamon, R. M., Manly, P. L., Dunham, D. W., Olson, R. W., Baggett, W. E., and Zeigler, K. W. (1989). The Diameter, Shape, and Albedo of 47 Aglaja. *Icarus* **81**, 375–385.

Millis, R. L., Wasserman, L. H., Franz, O. G., Bowell, E., Nye, R. A., Thompson, D. T., White, N. M., Hubbard, W. B., Eplee, R. E., Lebofsky, L. A., Marcialis, R. L., Greenberg, R. J., Hunten, D. M., Reitsema, H. J., Qian Bochen, Dunham, D. W., Maley, P. D., Klemona, A. R., and Yeomans, D. K. (1989). Observations of the 8 December 1987 Occultation of AG +40°0783 by 324 Bamberga. *Astron. J.* **98**, 1094–1099.

Wasserman, L. H., Bowell, E., and Millis, R. L. (1990). Occultations of Stars by Solar System Objects. VIII. Occultations of Catalog Stars by Asteroids, Planets, Titan, and Triton in 1990 and 1991. *Astron. J.*, in press.

Synthetic Aperture Planetary Radar Astronomy Using the Very Large Array

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(a) In this investigation we take advantage of the NASA installation of X-band receivers on all of the VLA antennas which was done for the Voyager encounter at Neptune. Since this is a DSN frequency we can use the Planetary Radar transmitter on the Goldstone 70 meter antenna to illuminate solar system objects. The VLA is then used in its synthetic aperture mode to spatially resolve the radar echoes. This is vastly superior to the monostatic, range-rings and doppler-strip technique of achieving resolution because it is free of ambiguities and images the entire planet simultaneously. Furthermore, the VLA has about 5 times the receiving sensitivity as the 70 meter making the VLA/Goldstone radar configuration the most powerful radar with full sky coverage.

(b) During the last yearWe were successful in getting a radar echo from Titan with this system. We found a high variability of the reflectivity over 3 consecutive days (90 deg of rotation) with the highest values consistent with those from Europa and Ganymede, i.e., icy surfaces, and the weakest consistent with reflectivities of the terrestrial planet surfaces. If large regions of liquid hydrocarbons are present on the surface they are in the form of lakes, not oceans. Considerable progress has been made on the interpretation radar maps of Mars from this instrument and a paper is ready for publication.

(c) We have planned another experiment on Titan for July, 1990 in which we will measure the radar reflectivity in both polarizations and will observe a new region of Titan's surface with some overlap with the region studied in 1989. The major part of the interpretation of the massive Mars radar data set will be completed in the next year. We have well bounded the "stealth" region on Mars which is unique in returning zero radar echo. Reflectivity theories for such a structure (which is almost certain to be a dust flow with a 1000 km scale) are under development and are a great challenge. A good theory is required to interpret the data in terms of the martian surface parameters such as density, depth of the deposit and electrical parameters.

(d) A Titan radar paper is in the galley stage at *Science*: "Radar Reflectivity of Titan" D.O. Muhleman, A.W. Grossman, B.J. Butler and M.A. Slade. The Mars radar images and some discussion will appear in the book: **Mars**, Arizona Press, in press. A paper for *Science* on the Mars radar work is essentially complete by Muhleman, Butler, Grossman and Slade. It will be submitted in May'90.

Submillimeter and Millimeter Observations of Solar System Objects

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(a) Several molecular species which are important in planetary atmospheres and comets have rotational transitions in the submillimeter and millimeter spectral range. The primary lines that can be observed from earthbased observatories are CO, HCN and, possibly H_2O.We exploit CO in particular in the atmospheres of Venus, Mars and Titan to study their compositions, temperature/pressure structures and circulation patterns, i.e. winds.

(b) Great progress has been made during the last year in interpreting the CO maps of Venus made with the Millimeter Array at the Owens Valley Radio Observatory during the inferior conjunctions of 1986 and 1988. Kathryn Pierce, a thesis student working with Prof. Muhleman, has developed wind maps which prove that the superrotational zonal winds extend through the altitude range from 75 km to at least 110 km. These winds are in excess of 100 meters/sec. Evidence exist in the data of the solar to anti-solar flow at the highest altitudes. Muhleman and Dr. R.T Clancy (LASP) have continued their (patient) systematic study of the CO (and its isotopes) distribution in the atmospheres of Venus and Mars. These data are inverted for temperature vs altitude and yield important information about atmospheric variations over long time periods that can not be studied from spacecraft (at least until MO is in orbit around Mars). A successful experiment to measure the CO abundance in the atmosphere of Titan was carried at the Caltech Submillimeter Observatory (CSO) on Mauna Kea in Sept 1989. The total CO abundance and its height distribution are important questions for the Cassini Mission. This work was done by Muhleman and Clancy. Arie Grossman completed a 2.8 millimeter map of the Saturn system which is a part of his thesis work that primarily involves VLA mapping of the system (supported on another NASA grant).

(c) Observations of Titan CO and HCN are planned for the CSO when Titan becomes a night object. These measurements are highly controversial and are important for the design of Cassini instruments. After two successful attempts on Venus, we feel that we really know how to map the wind fields on Mars with the CO (1-0) transition. A large campaign at OVRO will be mounted in the fall of 1990 to this effect. If successful, these will be the FIRST MEASUREMENTS OF MARS WINDS ever made!

(d) Bibliography: Clancy, R.T. and D.O. Muhleman, Correction regarding the Lellouch *et al.* (1989) analysis of Mars atmospheric ^{12}CO and ^{13}CO spectra, *ICARUS* in press 1989. Clancy, R.T. and D.O. Muhleman, Global changes in the 0-70 km thermal structure of the Mars Atmosphere, *J. Geophys. Res.* in press 1989. Grossman, A., D. Muhleman and G. Berge, High resolution microwave images of Saturn, *Science* **245**, 1211-1215, 1989 (partly supported by this grant).

Lunar and Planetary Studies

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Duane O. Muhleman, Peter Goldreich,
Andrew P. Ingersoll, and James A. Westphal

a) This grant supports some of the planetary astronomy work of 4 Professors from the planetary science department: Goldreich, Ingersoll, Westphal and Muhleman who is the administrative PI of this grant. Funding is used exclusively to support thesis research under the close supervision of the individual faculty members. Original earthbased observations are performed and remote sensing data from spacecraft are analyzed and interpreted.
b) Goldreich, together with graduate student Banfield and postdoctoral fellows Murray and Lonaretti have proposed that Triton was captured by Neptune after colliding with one of Neptune's primordial satellites, and showed that Triton's orbit could have evolved to its present unusual configurations due to tides raised in the satellite by Neptune; duringwhich Triton would have cannibalized most of the regular satellites. Muhleman, with graduate students A. Grossman and M. Hofstadter, have extensively observed the Saturn system and Uranus with the VLA at several frequencies to study the deep atmospheres of these planets and Saturn's rings. Hofstadter, as part of his thesis work, has discovered a deep circulation pattern in Uranus (to ~100 bars). Grossman, in his thesis, has discovered and analyzed banded latitude structures below the 1 bar level in Saturn's atmosphere and has greatly extended our understanding of Saturn's rings. Ingersoll has developed dynamical models for the atmospheres of Io and Triton and ,with R. Achterberg and T. Dowling, general circulation models of the giant planets. S. McMuldroch, a graduate student with Westphal, has investigated the spokes of Saturn's rings with earthbased telescopes and found a significant reduction in spoke contrast from the Voyeger images, indicating physical and temporal variations.
c) Goldreich's group will investigate perturbations by Neptune of the inner satellites (Banfield), the role of secondary orbit-orbit resonances on the current state of natural satellite systems (Malhotra) and the validity of the self-gravity model for the precession of narrow planetary rings (Goldreich and Longaretti). Ingersoll will continue to work with Muhleman and his students on circulation in the deep atmospheres of the giant planets. Additional VLA observations of Uranus and Neptune are planned. Muhleman's group will attempt to extend our knowledge of Saturn's rings from additional radar data combined with existing microwave emission data.

d) The following publications were primarily supported by this grant:
Goldreich's group: Goldreich, P., Murray, N., Longaretti, P.Y., and Banfield, D. (1989). Neptune's Story, *Science*, **245**, 500. Malhotra, R. and S. Dermott (1990). The role of secondary resonances in the orbital history of Miranda, *Icarus*, in press. Malhotra, R. (1990) Capture probabilities for secondary resonances, *Icarus*, submitted.

Ingersoll's group: Ingersoll, A.P., Io meteorology: How atmospheric pressure is controlled locally by volcanos and surface frosts, *Icarus* **81**, 298-313, 1989. Achterberg, R.K., and A.P. Ingersoll, A normal-mode approach to Jovian atmospheric dynamics, *J. Atmos. Sci.* **46**, 2448-2462, 1989. Dowling, T.E., and A.P. Ingersoll, Jupiter's Great Red Spot as a shallow water system, *J. Atmos. Sci.* **46**, 3256-3278, 1989. Ingersoll, Andrew P., Dynamics of Triton's atmosphere, *Nature*, in press, 1989.

Muhleman's group: Hofstadter, M.D. and D.O. Muhleman, Latitudinal variations of ammonia in the atmosphere of Uranus, *Icarus*, **81**, 296-412, 1989. Grossman, A.W., D.O. Muhleman and G.L. Berge, High Resolution microwave images of Saturn, *Science*, **245**, 1211-1215, 1989. Hofstadter, M.D., D.O. Muhleman and G.L. Berge, Vertical motions in the Uranian atmosphere as seen by radio observations. Submitted to *Icarus*, Oct. 1989.

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Study of Cometosheath Composition and Dynamics Using Data Obtained by the Giotto Ion Mass

Jet Propulsion Laboratory, California Institute of Technology

Marcia Neugebauer, Bruce E. Goldstein, and Raymond Goldstein

a. Strategy of Investigation: Data obtained by the Ion Mass Spectrometer flown on the Giotto spacecraft in March, 1986, are used for studies of the physics and chemistry of ions in a cometary coma.

b. Progress and accomplishments of prior year (3/89 - 3/90): (i) Data on the IMS/HERS response to low-velocity protons obtained during the 1988 recalibration of the spare Giotto/HERS sensor were analyzed, interpreted, and prepared for use in the computer software used to calculate physical parameters from the data. (ii) The final calibration data were used to calculate vector velocity, density, and temperature for each ion species. These data are being deposited in the International Halley Watch Archive. (iii) Compared the density, pitch-angle, and energy distributions of protons and water-group ions picked up by the solar wind upstream of Halley's bow shock. These results are strong evidence against the "expanding" halo model of the coma. (iv) Prepared a review paper on the interaction of the solar wind with active comets. (v) Analyzed some events in the IMS/HERS data which we interpret as the plasma signature of high-speed dust impacts on the spacecraft. (vi) Continued work on the analysis and modelling of the energetic ions seen in the inner Halley coma, particularly regarding the role of these ions in the plasma energy budget.

c. What will be accomplished this year: (i) The "final" reduced data for protons and alphas will be placed on the data tape containing merged plasma and field data observed by Giotto. This will allow determination of the total plasma environment, including the contributions of both solar wind and cometary ions, in the region between the bow shock and the cometopause. (ii) Write a paper that presents the reduced data on ion composition, velocity, density, and temperature described in (ii) above and compares the observations to available models, such as that by Schmidt et al. Where the data and the models disagree, we will work with the modelers to try to determine the principal cause(s) of the discrepancy. (iii) Complete papers on the fast ions seen inside the contact surface and on the dust-caused plasma.

d. Summary bibliography.

Papers published (3/89 - 3/90): (i) Eviatar, R. Goldstein, et al., Energetic Ion Fluxes in the Inner Coma of Comet P/Halley, *Astrophys. J.*, *339*, 545, 1989. (ii) Neugebauer et al., The velocity distributions of cometary protons picked up by the solar wind, *J. Geophys. Res.*, *94*, 5227, 1989. (iii) B. Goldstein, et al., Observations of a shock and a recombination layer at the contact surface of comet Halley, *J. Geophys. Res.*, *94*, 17251, 1989.

Papers submitted or accepted for publication: (i) Neugebauer, Spacecraft Observations of the Interaction of Active Comets with the Solar Wind, *Reviews of Geophysics*, accepted. (ii) Neugebauer et al., Comparison of Picked-up Protons and Water-Group Ions Upstream of Comet Halley's Bow Shock, *J. Geophys. Res.*, submitted. (iii) Neubauer, R. Goldstein, et al., Hypervelocity Dust Particle Impacts Observed by the Giotto Magnetometer and Plasma Experiments, *Geophys. Res. Lett.*, submitted.

The group also presented or co-authored 8 papers at the AGU Chapman Conference on Cometary Plasma Processes, Guildford, Surrey, England, July 17-21, 1989:

1989 Publications

Buti, B., and A. Eviatar, Plasma conductivity for Comet Halley's ionosphere, *Astrophys. J., 336,* L71, 1989.

Eviatar, A., R. Goldstein, D. T. Young, H. Balsiger, H. Rosenbauer, and S. A. Fuselier, Energetic ion fluxes in the inner coma of Comet P/Halley, *Astrophys. J., 339,* 545, 1989.

Goldstein, B. E., K. Altwegg, H. Balsiger, S. A. Fuselier, W.-H. Ip, A. Meier, M. Neugebauer, H. Rosenbauer, and R. Schwenn, Observations of a shock and a recombination layer at the contact surface of comet Halley, *J. Geophys. Res., 94,* 17251, 1989.

Neugebauer, M., Spacecraft Observations of the Interaction of Active Comets with the Solar Wind, *Reviews of Geophysics*, accepted for publication, 1990.

Neugebauer, M., B. E. Goldstein, H. Balsiger, F. M. Neubauer, R. Schwenn, and E. G. Shelley, The density of cometary protons upstream of comet Halley's bow shock, *J. Geophys. Res., 94,* 1261, 1989.

Neugebauer, M., A. J. Lazarus, H. Balsiger, S. A. Fuselier, F. M. Neubauer, and H. Rosenbauer, The velocity distributions of cometary protons picked up by the solar wind, *J. Geophys. Res., 94,* 5227, 1989.

Physical Processes in Comets

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A. STRATEGY Post-Halley, comets are known to be irregular objects, with most nucleus activity very localized and with the dust coma capable of fragmentation and appparently a source of gas. Older one-dimensional strategies which assume steady, isotropic outflow of material can give poor time-and-space-averaged results, at best. With two-dimensional data, images through interference filters, one can hope to see dust structures that give evidence of the proper geometry for data reduction, study gradients along the axes of symmetry as evidence of fragmentation, and seek evidence for gas abundance gradients associated with the dust. High quality data from brighter comets can then be used to suggest improved data reduction procedures for fainter ones. To obtain such data, large, image-quality interference filters have been procured for use with a CCD camera at Lick Observatory, where the scale of the 1m Nickel reflector is ideal for brighter comets. Whenever possible, data will be taken simultaneously with other telescopes and equipment (see below).

B. PROGRESS Good two-dimensional data was acquired at Lick Observatory on P/Brorsen-Metcalf under very difficult conditions (elong.=45°). Spinrad carried out simultaneous echelle spectroscopy on the 3m Shane reflector. New reduction techniques are being developed to process these results. The last of the older IR data acquired at the IRTF (Klemola, Borrelly, Brooks 2, etc.) is being reduced and prepared for publication. Forty-nine review papers from the Bamberg comet conference have been reviewed, accepted, and are in the final editing stages before publication by Kluwer Academic Press. The resulting book of 1000 pages, "Comets in the Post-Halley Era," should be a standard text and reference for years to come.

C. PLANNED A major observing program has been planned for Comet Austin, which is expected to be both bright and well placed in the sky. We expect to have simultaneous 1m and 3m time at Lick again, and we hope to have UV imaging (Lane) and near IR imaging (Crisp) at Table Mtn. Obs. on the same nights. Radio, Radar, and far IR are anticipated at nearly the same time at other facilities. New data reduction techniques will be developed both for this data and for the huge Halley database in the Halley Archive. The Bamberg conference volume should appear in late summer.

D. PUBLICATION Hanner,M.S., Newburn,R.L., Gehrz,R.D., Harrison,T., Ney, E.P., and Hayward,T.L.,"The Infrared Spectrum of Comet Bradfield (1987s) and the Silicate Emission Feature," Astrophys. J. 348, 312-321, 1990.

PUBLICATION

Hanner, M.S., Newburn, R.L., Gehrz, R.D., Harrison, T., Ney, E.P., and Hayward, T.L., "The Infrared Spectrum of Comet Bradfield (1987s) and the Silicate Emission Feature," Astrophys. J. 348, 312-321, 1990.

Infrared Observations of Planetary Atmospheres

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(a) The goal of this effort is to acquire infrared astronomical data which supply key information on structures, compositions, and, indirectly, dynamics of planetary atmospheres. Our investigation is intended to complement and support planetary spacecraft experiments by providing (1) a quantitative baseline required for designing optimum spacecraft *in situ* and remote sensing experiments, and (2) extension of observational coverage into spatial, temporal, spectral range and spectral resolution domains not covered by spacecraft experiments. We will make observations this year which will supplement Voyager Neptune atmospheric observations and which will support the Galileo mission at Jupiter and the proposed Cassini mission to the Saturn system.

(b) We continued thermal infrared mapping of Jupiter and Saturn at 4.8-22 μm to derive temperature structures and information on cloud properties and composition. For Jupiter, all longitudes were mapped once per year and a program was initiated to acquire maps monthly with more limited spectral and longitude coverage. We developed techniques for routine geometric rectification and calibration of the imaging data. We published a low-resolution spectrum of Uranus at 4.7 - 5.2 μm and filtered radiometric data of Uranus and Neptune in the range of 7 - 32 μm to verify the calibration scale of earlier survey spectra (Orton *et al.*, 1987, Icarus 70, 1)

(c) We will continue mapping of Jupiter and Saturn in both the thermal and near-infrared, with additional emphasis on monitoring short-term behavior in addition to wavelength- and longitudinal-intensive coverage at opposition, paying particular attention to dramatic changes in the morphology of the jovian stratosphere in recent months. We will examine in more detail the extent to which phenomena observed in thermal infrared and visual/near-infrared data are correlated. We propose to obtain near-infrared images of Neptune, in order to gain additional spectral information about the temporal and spatial variability and stratigraphy of its discrete atmospheric features. We will provide thermal infrared observations of Venus to coincide with the Galileo encounter to support PPR radiometric science. We will initiate high-resolution spectroscopic studies of the planets, starting with Neptune and we will initiate studies of Titan at sub-millimeter through millimeter wavelengths.

(d) Orton, G. S. and C. A. Kaminski 1989. An exploratory 5-μm spectrum of Uranus. *Icarus* 77, 109-117; Beebe, R., G. S. Orton and R. A. West 1989. Time-variability of clouds and temperatures: An observational perspective. In *Time-Variable Phenomena of the Jovian System* (Belton, Hunt, and West, eds.), NASA Special Publication 494, in press.

Radar Investigation of Asteroids and Planetary Satellites

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a. **Strategy**: Radar reconnaissance of near-Earth asteroids, mainbelt asteroids, the Galilean satellites, the Martian satellites, and the largest Saturnian satellites, using the Arecibo 13-cm and the Goldstone 3.5-cm systems. Measurements of echo strength, polarization, and delay/Doppler distribution of echo power provide information about dimensions, spin vector, large-scale topography, cm-to-m-scale morphology, and surface bulk density. The observations also yield refined estimates of target orbital elements.

b. **Accomplishments**: Radar signatures have been measured for 34 mainbelt asteroids and 23 near-Earth asteroids since this task began ten years ago. The dispersion in asteroid radar albedoes and circular polarization ratios is extreme, revealing huge differences in surface morphologies, bulk densities, and metal concentration. Echoes from the near-Earth asteroid 1627 Ivar, whose orbit crosses the Earth's, reveal it to be about twice as long as it is wide, with a maximum dimension no less than 7 km and probably within 20% of 12 km. Ivar's surface is fairly smooth at cm-to-m scales but appears irregular and nonconvex at km scales. The first radar detection of Phobos indicates that Mars's largest satellite has surface characteristics very different from those of the Moon and most near-Earth asteroids, but similar to those of large, C-class asteroids. The radar signatures of Europa, Ganymede, and Callisto have recently been measured at 3.5, 13, and 70 cm and are extremely unusual at all three wavelengths.

Observations of the near-Earth asteroid 1989 PB, conducted shortly after its optical discovery, yield a sequence of delay-doppler images that reveal it to consist of two distinct lobes that appear to be in contact, or nearly so. 1989 PB may have formed as a result of collisional disruption of a much larger object in the main asteroid belt, when two fragments that had been dispersed by that collision at low relative velocity became gravitationally bound to each other.

c. **Anticipated Accomplishments during 1990**: 1) Publication of the initial results of the 1989 PB experiment; reconstruction of the object's three-dimensional shape from inversion of the delay-doppler data. 2) 13-cm observations of Phobos and Deimos during the closest approach of Mars visible to Arecibo until 2005. 3) First attempts to measure the 3.5-cm radar properties of mainbelt asteroids.

d. **Publications**:

Ostro, S. J., R. F. Jurgens, D. K. Yeomans, E. M. Standish, W. Greiner (1989). Radar detection of Phobos. Science **243**, 1584-1586.

Ostro, S. J., D. K. Yeomans, P. W. Chodas, R. M. Goldstein, R. F. Jurgens, T. W. Thompson (1989). Radar observations of asteroid 1986 JK. Icarus **78**, 382-394.

Ostro, S. J. (1989). Radar Observations of Asteroids. In Asteroids II (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.). Univ. of Arizona Press, pp. 192-212.

Magnusson, P., M. A. Barucci, J. Drummond, K. Lumme, S. J. Ostro, J. Surdej, R. Taylor, V. Zappala (1989). Determination of asteroid shapes and pole orientations. In Asteroids II (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.). Univ. of Arizona Press, pp. 66-97.

Ostro, S. J., K. D. Rosema, R. F. Jurgens (1990). The shape of Eros. Icarus, in press.

Ostro, S. J., and E. M. Shoemaker (1990). The extraordinary radar echoes from Europa, Ganymede, and Callisto: A geological perspective. Icarus, in press (1990).

Ostro, S. J., D. B. Campbell, A. A. Hine, I. I. Shapiro, J. F. Chandler, C. L. Werner, K. D. Rosema (1990). Radar Images of Asteroid 1627 Ivar. Astron. J., in press.

Spectroscopic Observations of the Planets

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a) Strategy: This program makes use of spectrographs at major telescopes to study the composition and structure of planetary and satellite atmospheres, the properties of condensed volatiles on icy satellites, and isotope ratios in comets. Optical and infrared wavelengths are explored, with occasional recourse to radio frequencies.

b) Progress and Accomplishments in 1989: Working with Catherine de Bergh, Barry Lutz and Jean Pierre Maillard in October 1988, we successfully identified the presence of Doppler shifted HDO lines from the ν_1 band at 3.6 μm in the spectrum of Venus. This was the first detection of deuterium on Venus by remote spectroscopy. In November of 1989, we repeated these observations, with the additional participation of David Crisp and Bruno Bezard. Spectra of the darkside of Venus near 2.35 μm revealed both H_2O and HDO lines which are presently being analyzed to obtain a value for D/H.

In July of 1989 with Caitlin Griffith, we obtained spectra of Titan with the Cooled Grating Spectrometer at the IRTF at selected wavelengths in the 1.0 - 2.5 μm region. Subsequent analysis by Griffith has substantiated and quantified our previous contention that there are spectral windows in this region that allow observations of Titan's lower atmosphere, possibly extending to the surface itself.

In December, with John Glaspey, we recorded the spectrum of Comet Aarseth-Brewington near 4735 Å, at a resolution of approximately 18,000. This spectrum clearly shows the (2,0) $^{12}C^{13}C$ band head and allows a good correction to be made for overlap with NH_2 emission lines. The analysis of this spectrum is currently underway to obtain a value of $^{12}C/^{13}C$ in the coma of this comet.

c) Plans for 1990: The arrival of Comet Austin provides a rare opportunity for high resolution spectroscopy. Our goal is to test again the value of $^{12}C/^{13}C$ at still higher resolution and to extend this work to other isotopes if possible. The data on isotopic ratios in comets is still meager and mostly of poor quality, so this opportunity must be exploited to the utmost if the comet is sufficiently bright.

We have also applied for time to record the spectrum of Triton between 1.4 and 2.5 μm with the FTS at the CFHT. The Voyager flyby of this remarkable object in August of 1989 left many questions unanswered. Among them is the composition of the surface materials, specifically the question of whether or not solid CO or various hydrocarbons may be present. We should be able to improve upon currently available spectroscopic resolution by at least a factor of three, which will make all the difference in the identification of possible condensed compounds.

d) Summary Bibliography:

"The Composition of Outer Planet Atmospheres" (with D. Gautier) in PLANETARY ATMOSPHERES, eds. S. K. Atreya, J. B. Pollack, and M. S. Matthews, University of Arizona Press (1989) pp 487-512.

"Spectroscopy of Emission Features Near 3 μm in Comet Wilson (1986 1)" (with T. Y. Brooke, R. F. Knacke, and A. T. Tokunaga), Astrophys. J. 336, 971-978 (1989).

"Titan: Some New Results" (with D. Gautier), Adv. Space Res. 9, 273-278 (1989).

"Measurements of the D/H Ratio in Planetary Atmospheres by Ground Based Infrared Spectroscopy" (with C. de Bergh, B. L. Lutz and J. P. Maillard, in Proc. 22nd Eslab Symposium on Infrared Spectroscopy in Astronomy, Salamanca, Spain, ESA SP 290 (Sept. 1989).

Stellar Occultations by Planetary Rings

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a. *Objective* : To reduce and synthesize near infrared observations of the 3 July 1989 occultation of 28 Sagittarii by Saturn and its rings made from 7 different telescopes spread around the world (2 in Chile, 1 in Hawaii, 1 in Mexico, and 3 in Tucson); and to combine these observations with Voyager data to study the dynamical state of Saturn's rings. This unique event, which occurred 8 years after the Voyager flybys, provides a temporal baseline over which kinematical and dynamical phenomena within the rings may be examined in detail.

b. *Progress* : Observations were successfully made at all 7 sites. Standard aperture photometry was used at 4 of them: CTIO (Chile), San Pedro Martir (Mexico), MMT (Tucson), and Catalina Station (Tucson). Rapid, 2-dimensional imaging was used at the remaining 3: Las Campanas (Chile), Kitt Peak (Tucson), and UKIRT (Hawaii). Only the CTIO and San Pedro aperture data were relatively problem free. In the last 5 months (the period of time so far funded by this grant), substantial progress has been made in cleaning up the remaining aperture data sets, developing software for batch-processing of the imaging data, and in refining the astrometry to the point where ring features may be absolutely located to an accuracy of several kilometers.

c. *Proposed work* : In the following year, I expect to: i) Continue the reduction of all data sets, especially the 2-dimensional imaging data which will be most time-consuming. Remove from each resulting occultation scan the effects of finite stellar diameter, the limiting factor in radial resolution. ii) Combine the 14 separate cuts through the rings (7 ingress and egress occultations) with Voyager imaging, radio science, and stellar ring occultation data, referencing all to a common coordinate system; iii) Re-examine the dynamics of Saturn's eccentric features (Porco, 1989; Porco *et al.* , 1984); search gap edges for edge waves indicative of shepherding satellites; fill out the particle size distribution; refine our knowledge of Saturn's gravitational harmonics by improving tenfold the precision of ringlet kinematics (Nicholson and Porco, 1988).

d. *Summary bibliography* : 1 paper; 3 abstracts; 1 oral presentation.

RELEVANT BIBLIOGRAPHY, 1989-1990

Porco, C. C. (1990) Narrow rings: Observations and theories. *Advances in Space Research* **10**, 730-737.

Atmospheres of Mercury and the Moon

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a. Strategy: The sodium and potassium atmospheres of Mercury and the Moon are mapped using spectroscopic measurements of resonance scattered sunlight. The objective is to define the sources and sinks for these atmospheric constituents, and in so doing, provide a better understanding of atmospheric processes on these bodies, which are unique in that their atmospheres consist solely of an exosphere with the planetary surface at its base.

b. Progress: A technique was developed for obtaining two-dimensional images of the sodium emission from Mercury. Images on six different dates over the period from November 1988 to August 1989 showed that the distribution of sodium emission sometimes changes on a daily basis, and that it is often concentrated in small regions near the north and south poles. These effects are believed to be caused by interactions between the sodium atmosphere and the magnetosphere of the planet. With better understanding of the processes involved, it is possible that observations of the sodium atmosphere may provide a tool to monitor the magnetosphere of Mercury.

Observations of the sodium atmosphere of the Moon were made at different lunar phases. It was found that the sodium atmosphere extends at least to 1200 km above the lunar surface, which shows that a large fraction of the sodium atoms have high kinetic temperatures. Preliminary analysis seems to show that the effective scale height of sodium is smaller over the terminator than over the subsolar point.

c. Plans: The ratio of sodium to potassium is much larger on Mercury (about 80/1) than it is on the Moon (about 7/1). Reasons for this difference are not understood. Comparison of the planet-wide distributions of these elements will provide a test of various possible explanations. For this reason, same-day observations of the sodium and potassium distributions on Mercury are planned. Additional lunar measurements will focus on measurements of potassium in order to make comparisons with the sodium data in hand.

Publications

Morgan, T.H., H.A. Zook, and A.E. Potter. 1989 "Production of Sodium and Potassium Vapor from the Exposed Regolith in the Inner Solar System" Proc. Planet. Soc. Conf. 19th, Cambridge Univ. Press, London/New York in press

Killen, R.M., A.E. Potter, and T.H. Morgan. "Spatial Distribution of Sodium Vapor in the Atmosphere of Mercury" Icarus. In press.

Potter, A.E. and T.H. Morgan. "Evidence for Magnetospheric Effects on the Sodium Atmosphere of Mercury" Science. In press.

Fabry-Perot Ground-Based Observations of Comets And the Jupiter Plasma Torus

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a. Strategy: Our group has been investigating aspects of cometary and magnetospheric physics by means of ground-based astronomical spectroscopy. We have used high-throughput dual-etalon Fabry-Perot spectrometers (usually at the McMath solar telescope on Kitt Peak) to obtain very high resolution spectra of atomic, molecular, and ionic emission lines from the diffuse gases and plasmas associated with comets and the Jupiter plasma torus. The Fabry-Perot spectrometers can also be used with a CCD camera to obtain images of these extended emission sources in individual spectral lines at high spectral resolution.

b. Accomplishments: During the past year, we completed several papers (to be published in Icarus) on the results of our Comet Halley observations. The most recent paper presented our results on emission spectra from H_2O^+ ions in the coma and along the plasma tail. Abundances and velocity distributions of the cometary H_2O^+ were obtained from the emission line intensities and wavelength profiles, respectively. Tailward accelerations of the plasma were obtained from the variation of Doppler shift along the tail.

We carried out a program of observations of the Jupiter plasma torus during November and December, 1988 at the McMath solar telescope on Kitt Peak in Arizona. This work was done in collaboration with Dr. Ron Oliversen from GSFC. We obtained an extensive series of Fabry-Perot scans and Fabry-Perot/CCD images of the torus in the [SII]6716,6731 and [SIII]9531 emission lines. This data set is being analyzed for structural and temporal variations in the torus.

We hosted a multidisciplinary workshop on the torus and neutral clouds at the University of Wisconsin-Madison, during the week of July 17, 1989. This workshop was the first in the 15-year history of torus/clouds observations to be focussed on a comparison of observations of the torus and neutral clouds in order to try to obtain a synthesis of the broad spectrum of observations.

c. Anticipated Accomplishments: Our November-December, 1988 Jupiter plasma torus observations will be compared with our earlier work on the torus in 1981, 1982, 1984, and 1987. We will also compare our results with those of other observers, especially Drs. John Trauger of JPL and Nick Schneider of the University of Arizona, who also obtained observations of the torus in December, 1988.

A new comet, discovered by Rodney D. Austin in December 1989, promises to be the most exciting comet for observers since Comet West in 1976. Comet Austin (1989C1) is expected to be brighter than Comet Halley was in 1986.

We have been scheduled for 33 nights of observing time in April and May, 1990 at the McMath telescope on Kitt Peak for Fabry-Perot observations of Comet Austin. High resolution Fabry-Perot spectra and images of Comet Austin will be obtained for the following purposes.

1. To study the interaction of the solar wind with the cometary plasma, using emission spectra and images of H_2O^+ ions in the coma and along the comet's plasma tail.

2. To measure the production rate of atomic hydrogen, using Hα emission spectra from the hydrogen cloud surrounding the comet. The hydrogen production rate determines the gaseous H_2O production rate.

3. To obtain information on molecular photodissociation reactions leading to the production of oxygen atoms which are the sources of cometary 6300 Å emission. The observed 6300 Å spatial distributions can be modeled to provide improved values of photodissociation scale lengths of important cometary molecules such as H_2O, and also provide values of the production rates of oxygen and H_2O. The H_2O production rates obtained from our oxygen 6300 Å data can then be compared with the production rates from our hydrogen Hα data to see if they are consistent, or to disclose discrepancies which require further investigation.

d. Publications:

K. Magee-Sauer, F. Scherb, F. L. Roesler, and J. Harlander, "Fabry-Perot Observations of NH_2 Emission from Comet Halley", Icarus, 82, 50 (1989).

K. Magee-Sauer, F. Scherb, F. L. Roesler, and J. Harlander, "Comet Halley $O(^1D)$ and H_2O Production Rates", Icarus, 83, xx (1990).

F. Scherb, K. Magee-Sauer, F. L. Roesler, and J. Harlander, "Fabry-Perot Observations of Comet Halley H_2O^+", Icarus, 84, xx (1990).

Radar Studies in the Solar System

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a) We are engaged in a study of the solar system by means of ground-based radar. We have concentrated on (i) developing the ephemerides needed to acquire radar data at Arecibo Observatory and (ii) analyzing the resultant data to: test fundamental laws of gravitation; determine the size, shape, topography, and spin vectors of the targets; and study the surface proportion of these objects, through their scattering law and polarization characteristics.

b) We have actively engaged in observations of asteroids and comets, both as systematically planned targets and as "targets of opportunity." A striking example of the latter was asteroid 1989 PB, which was discovered optically on 1989 August 9 and found to be rapidly approaching the Earth. Our colleague S. J. Ostro had observing time available at Arecibo on August 19-22, when the asteroid would be within the Arecibo declination window, and we made daily ephemeris refinements based on the available optical data beforehand and on the preliminary radar data during the observatory run. The result was a remarkable picture of an asteroid bifurcated into two distinct lobes and spinning with a period of about four hours. The observing program covered five other asteroids besides 1989 PB, and also the four Galilean satellites of Jupiter around the 1989-1990 opposition. In addition, progress was made in our ongoing effort to obtain "closure point" observations of Mercury, both at Arecibo and at the Goldstone radar operated by JPL. Finally, we have continued the analysis of radar data and prepared articles for publication in collaboration with our colleagues. One on asteroid 1627 Ivar is in press, and two others are in near-submission form, one on the spin vector of Venus and one on asteroid 1989 PB.

c) We plan to continue our activities in this field, both by obtaining radar observations of asteroids, comets, planets, and satellites and by analyzing the data. In particular, observations are planned for two comets and for the satellites of Mars and Jupiter, as well as a selection of asteroids and planets. We plan to refine the spin vector of Venus on the basis of recently acquired data; this will be important in the interpretation of results from the Magellan mission.

Infrared Imaging of Planets

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a). This work exploits the good seeing and the dry atmosphere of the Mauna Kea Observatory for high resolution planetary imaging observations at infrared wavelengths. We utilize facility IR arrays on the 3.8-m UKIRT and 3.0-m NASA-IRTF, together with a NICMOS 256 x 256 pixel array on the UH 0.6-m and 2.24-m telescopes.

b). High resolution observations of near infrared emission from the night side of Venus were obtained in conjunction with the Galileo flyby of that planet in February 1990. The images were acquired using the 256 x 256 pixel NICMOS array at 1.7 and 2.3 μm, in a variety of polarizations. The images are taken as part of a program organized by D. Crisp of JPL.

Thermal infrared images of comet Brorsen-Metcalf were combined with images of the scattered light to produce a map of the albedo of the coma dust grains. We find a centrally depressed albedo with low albedos running along the tail. The map suggests that large cometary grains (radii > 10 μm) have lower albedo than the ~ 1 μm sized grains seen at optical wavelengths, perhaps because of multiple scattering in open structures. This work was presented by IfA graduate student Susan Ridgway at the "Astrophysics With Infrared Arrays" conference in Tucson.

Images of cometary dust continua at near infrared wavelengths were obtained at the UKIRT with a 58 x 62 InSb camera. The images are being used to study color gradients in the comae. We expect color gradients to arise both from particle sorting by radiation pressure, and from compositional gradients associated with volatile grains. The technical difficulties inherent in searching for small color differences on the steep surface brightness profiles of rapidly moving comets are formidable. However, small color differences have been confidently identified, and are the subject of numerical modelling at the time of writing.

The co-I gave an invited talk entitled "Planetary Astronomy With Infrared Arrays" at the "Astrophysics With Infrared Arrays" conference in Tucson, February 19 - 22.

c). This research was funded as a one - year proposal.

d). **Bibliography**

D. C. Jewitt (1990), "Planetary Astronomy with Infrared Arrays", invited review for the Astrophysics with Infrared Arrays Conference, Tucson, February 19-23 1990. In Press.

S. E. Ridgway, D. C. Jewitt, H. Campins, J. Luu, M. Joy, C. Sisc, and C. Telesco (1990), "An Albedo Map of Comet Brorsen-Metcalf", in Astrophysics with Infrared Arrays Conference, Tucson, February 19-23 1990. In Press.

Studies in Planetary Sciences

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Remnant circumstellar material is that which remains in the form of a disk after planet formation. An extensive disk of remnant material has been detected optically around the nearby star, Beta Pictoris. Our multispectral and polarimetric observations indicate that the disk is composed primarily of small grains of carbonaceous type material, perhaps similar to that which makes up comet nuclei. An optical search for remnant circumstellar material around other nearby stars has yet to detect a similar system.

During the past year, an analysis of all of our multispectral and polarimetric data has been completed by B. Smith and J. Fountain and the results prepared for publication. A dynamical modelling program involving resonance blocking by planetary bodies where strong non-gravitational forces are also present is being developed by Smith and F. Roques to explain the highly depleted region within 15 to 20 au of Beta Pictoris. A careful examination of the region surrounding 46 southern hemisphere stars within 50 parsecs has been completed by Smith and Fountain. No material in excess of 0.1 of the Beta Pictoris disk density has been found.

This year a comprehensive optical/ir model of the Beta Pictoris disk will be published. Development of the dynamical model will be continued. Analysis of the remaining 75 of the 121 observed candidate stars should be completed and the results published. New observations of the Beta Pictoris disk will include high resolution imaging (along with several other candidate stars) with the Hubble Space Telescope (Smith), a search for CO at millimeter wavelengths (115 and 331 GHz) using the SETS submillimeter telescope at ESO (with I. Grenier) and proposals for studies in the infrared at Mauna Kea and ESO.

A Continued Program of Planetary Study At McDonald Observatory

McDonald Observatory
University of Texas

Harlan J. Smith, William D. Cochran, Edwin S. Barker,
Anita L. Cochran, and Laurence M. Trafton

a. This program conducts solar system research in support of NASA missions and of general astronomical interest. Investigations of the composition, physical characteristics, and changes in solar system bodies are conducted primarily utilizing facilities of McDonald Observatory, but also utilizing various space vehicles where appropriate.

b. We have discovered a new absorption feature in Io's near-infrared spectrum, which is not present in the spectra of the other Galilean satellites. Unlike the absorption features discovered at longer wavelengths, this feature at 2.125μm is very narrow, with FWHM <25Å. This exciting result suggests the presence of another gaseous component to Io's atmosphere because such a narrow feature is very unlikely to arise from a pure solid material. Jupiter's 2μm aurorae were clearly visible in December 1989, after they had been reported absent in September by other observers. The rotational temperature of auroral H_2 was found to vary by nearly a factor of 2, indicating strong temporal variability. One of the unidentified emission lines which we had discovered in the Jovian aurorae has been identified as H_3^+. Other sets of Jovian auroral emission lines exhibiting different spatial and temporal behavior from the H_3^+ lines remain to be identified. We have determined new scale lengths for the creation and destruction of cometary NH and NH_2. We have shown that NH_2 can not be the dominant parent for NH. Our observations of comet Brorsen-Metcalf resulted in the first detections of CH at large radial distances from the nucleus of a comet. Models of these data seem to support CH_4 as the grandparent of CH. We detected no transit events of the star HD114762 by any unseen planetary companion. Although this negative result is disappointing, the real significance of this work is that we have clearly demonstrated the feasibility of using the photometric technique to search for transits of candidate planetary companions to nearby stars. The McDonald Observatory Planetary Search program has continued its extremely high precision radial velocity measurements on 33 nearby solar type stars, to detect Jovian size planets in orbit around them. We are now building a stabilized I_2 gas absorption cell, which should improve our measurement precision to better than $10\,\mathrm{m\,s^{-1}}$. A small amount of absorbing haze particles in Uranus' stratosphere is required to match IUE data for Uranus' UV spectrum. These results are consistent with microphysical models in which aerosols are produced in the stratosphere by photochemical processing of hydrocarbons. We have shown that the postperihelion and seasonal dependence of Pluto's atmosphere and surface ice compostion can be quite complex if two or more volatile fases make up the atmosphere. For on narrow range of parameters, the atmnosphere hardly freezes out at aphelion.

c. We will obtain spectra and images of comets brighter than mag. 17.5 as a follow-on to our earlier Faint Comet Survey. With these data, we will study the correlation of the minor species (NH, CH, and NH_2) with the strong OH features. We will also conduct a preliminary search for Kuiper belt comets, and will look for remnants of cometary activity among near-Earth asteroids. We will continue our survey for extra-solar planetary systems with our new instrumentation with significantly improved measurement precision. We will be improving the orbital phase coverage of the unidentified feature we discovered in Io's K band spectrum and will also continue the search of the K band region for undiscovered features to help in the identification. We will continue to monitor the spatial and temporal variability of the Jovian aurorae in the 2 micron region and begin the search for aurorae on other planets. We will begin the post-perihelion observations of the Pluto-Charon system in order to measure expected post-perihelion phenomena diagnostic of Pluto's atmospheric bulk and the thermal properties of the surface.

d) Summary Bibliography

1. Published Papers

   (a) Cochran, A. L., Green, J. R., and Barker, E. S. "Are Low Activity Comets Intrinsically Different From More Active Comets?" *Icarus* **79** 125-144, 1989.

   (b) Kim, S. J., A'Hearn, M. F., and Cochran, W. D. "NH Emission in Comets: Fluorescence vs. Collisions" *Icarus* **77** 98-108, 1989.

   (c) Smith, H. J. "Understanding the Universe - Challenges and Directions in Modern Observational Astronomy" Chapter in *Cosmic Perspectives* Cambridge University Press, pp 77-96, 1989.

   (d) Smith, H. J. "Overview of Lunar-based Astronomy" In *Future Astronomical Observatories on the Moon* (NASA Conf. Pub. 2489), ed. J. Burns and W. Mendell, 37-42, 1988.

   (e) Smith, H. J. and Barker, E. S. "Site, Weather and Seeing Conditions for the SST " In *Proc. of ESO Conference on Very Large Telescopes and their Instrumentation* Pub. ESO, Garching, pp 907-916, 1988.

   (f) Stern, S. A., Skinner, T. E., Brosch, N., Van Santvoort, J., and Trafton, L. M. "The UV Spectrum of Pluto-Charon: IUE Observations from 2600-3100Å" *Astrophys. J. (Letters)* **342** 533-538, 1989.

   (g) Stern, S. A., Skinner, T. E., Brosch, N., Van Santvoort, J., and Trafton, L. M. "The First UV Spectrum of Triton: IUE Observations from 2600-3200Å" *Astrophys. J. (Letters)* **341** L107-L110, 1989.

   (h) Trafton, L. "Observational Studies of Collision-Induced Absorption in the Atmospheres of the Major Planets" *Spectral Line Shapes* **5** 755-776, 1989.

   (i) Trafton, L. "Pluto's Atmosphere Near Perihelion" *Geophys. Res. Letters* **16** 1213-1216, 1989.

   (j) Trafton, L., Lester, D. F., and Thompson, K. L. "Unidentified Emission Lines in Jupiter's Northern and Southern 2 Micron Aurorae" *Astrophys. J. (Letters)* **343** L73-L76, 1989.

2. Submitted Papers

   (a) Cochran, A. L. "Are All Comets Created Equal?" In *Asteroids, Comets, Meteors III* in press.

   (b) Cochran, A. L. "Methods for Determining the Water Production Rates in Comets" In *Asteroids, Comets, Meteors III* in press.

   (c) Cochran, W. D. and Cochran, A. L. "NH_2 in Comet Halley" In *Asteroids, Comets, Meteors III* in press.

   (d) Cochran, W. D., Wagener, R., Caldwell, J., and Fricke, K. H. "The Ultraviolet Continuum Albedo of Uranus" *Icarus* in press.

   (e) Hatzes, A. P. and Cochran, W. D. "The Spectral Variability of Arcturus" *Ap.J.* submitted.

   (f) Smith, H. J. "A Decade of Cost-reduction in Very Large Telescopes (The SST as Prototype of Special-Purpose Telescopes)" In *Proc. of Symposium on JNLT and Related Engineering Developments* Tokyo, in press.

   (g) Robinson, E. L., Cochran, A. L. Cochran, W. D., Shafter, A. W., and Zhang, E.-H. "A Search for Eclipses of HD114762 by a Low-Mass Companion" *Astron. J.* in press.

   (h) Trafton, L. "A Two-Component Volatile Atmosphere for Pluto I. The Bulk Hydrodynamic Escape Regime" *Ap. J.* in press.

   (i) Trafton, L. "Planetary Atmospheric Structure and Energy Transfer" In *The Reference Encyclopedia of Astronomy and Astrophysics* (ed. S. Maran) in press.

Radio Astronomical Studies of Comets With the Very Large Array

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a) Brief statement on strategy of investigation: Radio observations of comets probe deep into the coma region. We use radio interferometry to study the composition, velocity distribution, maser excitation, and plasma interactions of cometary gas. We have worked with Prof. I. de Pater (Berkeley) to map OH emission and detect formaldehyde (H_2CO) emission from several comets, including Comet Halley. As future comets appear, we plan to continue our radio interferometric observations and compare them to the Halley results.

b) Progress and accomplishments of prior year: We have completed the reduction of the OH data from Comet Halley and published the final.results (1990, de Pater, Palmer, and Snyder). We are reducing the OH data for Comet Liller (1988a). We have completed the reduction of the Comet Machholz H_2CO data and published the final results (1990, Snyder, L. E., Palmer, P., and de Pater). We used the VLA to search Comet Brorsen-Metcalf for cyanoacetylene (HC_3N), but the data reduction is not yet finished.

c) What will be accomplished this year, as well as how and why: P. Palmer, L.E. Snyder, I. de Pater, F. P. Schloerb, and Mike A'Hearn plan to observe HCN emission from Comet Austin (1989c1) simultaneously with the three element millimeter array of the BIMA consortium at Hat Creek and the FCRAO 14-m telescope at U. Mass. By combining the array data with the 14-m data, it will be possible to approximately double the resolution of the 14-m telescope. For observations conducted between ≈ April 15 and May 6, the linear resolution at the comet would be of the order of the scalelength of HCN. During a significant part of the radio observational period, M. A'Hearn expects to obtain simultaneous, high resolution optical CN images with a CCD detector. HCN has often been suggested as the parent molecule of CN, and with the detection of HCN in Comet Kohoutek by Huebner, Snyder, and Buhl (1974, Icarus 23, 580) this view gained a more firm basis. But, in later studies of Comet Halley by F. P. Schloerb and collaborators at FCRAO and by J. Crovisier and collaborators at IRAM, it became clear that the uncertainty in cometary production rates ultimately prevents a definite conclusion from observations that do not spatially resolve the comet. Another development was an optical image of Comet Halley obtained by M. A'Hearn which showed a spiral structure in CN. Because the spiral structure extended over a distance which was long compared with the scalelength of HCN, it again raised serious questions about the parent molecule of the optical CN. We believe that the best way to resolve this long-standing problem is to conduct carefully coordinated imaging of both HCN and CN. The successful completion of this proposal would produce the first ever HCN images of a comet and the first simultaneous study of a cometary mother: daughter species.

d. Summary bibliography:

de Pater, I., Palmer, P., and Snyder, L. E., 1990, "A Review of Radio Interferometric Imaging of Comets", in Comets in the Post-Halley Era, eds. R. L. Newburn, M. Neugebauer, and J. Rahe (Dordrecht: Kluwer), in press.

Palmer, P., de Pater, I., and Snyder, L. E., 1989, "Observations of the OH Emission from Comet Wilson (1986l): The Value of High Resolution in Both Spatial and Velocity Coordinates", Astron. J., **97**, 1791.

Snyder, L. E., Palmer, P., and de Pater, I., 1990, "Observations of Formaldehyde in Comet Machholz (1988j)", Icarus, in press.

Snyder, L. E., Palmer, P., and de Pater, I., 1990, "Comet Halley and Interstellar Chemistry", in Proceedings of Pacifichem '89 Symposium No. 228, Chemistry and Spectroscopy of Interstellar Molecules, ed. N. Kaifu (University of Tokyo Press), in press.

Planetary Astronomy

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a) Strategy

A wide range of observational studies are carried out to improve our understanding of the ring systems and small bodies in the outer solar system. Using the recently introduced Cassegrain near infrared camera on the Hale 200-inch telescope infrared observations are made of planets, satellites, and ring systems in the outer solar system. Heavy use is made of imaging at 2.2 μm, because the giant planets are extremely dark at this wavelength, so that close objects that are faint can be more easily detected. In addition, the plate material of the PSSII survey is being used to search for new comets and asteroids.

b) Accomplishments

In April 89 and again in July 89 we searched for the "ring arcs" and sheparding satellites in the Neptune system at 2.2 μm prior to the Voyager Neptune encounter. None of the rings or Neptune satellites detected by Voyager was found on the images. These images, taken in excellent seeing, revealed the presence of a stationary bright region near the northern limb and several bright spots in the southern hemisphere that rotate with the planet.

We observed the occultation of the bright star 28 Sgr by the Saturn ring system using the near infrared camera on the 200 inch telescope. Images were obtained at 10 frames/second. In addition to probing the structure of the rings these data will permit the analysis of the material in the Saturn ring system that is in the size range 1-30 cm.

The scanning of the plates of the second Palomar Sky Survey has continued with the goal of finding new asteroids and comets. One near earth asteroid, 1989 DA, was discovered in the last year.

c) Anticipated Accomplishments

We shall continue the observational programs carried out in the last year. We shall image Neptune both to monitor the "weather" on this planet and to attempt to recover the brightest of the satellites discovered by Voyager. We shall use images of Uranus in the 2 μm atmospheric window to search for the predicted limb brightening of the planet in molecular features in order to refine the model of the atmosphere of this planet.

The plate material of the second Palomar Sky Survey will be scanned for new asteroids and comets.

Spatially Resolved Quantitative Spectroscopy of Comets

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a. Strategy: The objectives of my cometary research are to gain indirect knowledge of the chemical composition of cometary nuclei. This can be done through conventional, high-resolution spectroscopy and indirectly by imaging the dissociation radicals in the outflowing cometary comae.

b. Accomplishments: Two dimensional CCD images of Comet P/Brorsen-Metcalf were obtained using the Lick 1-m reflector on three nights in late August 1989. The images were obtained through high-quality optical interference filters in the light of the CN and C_2 radicals, as well as a line-free segment of the comet's red continuum. The goal of the analysis will be to study the gas production rates, coma asymmetries, and to eventually model radial gradients in the dust and gas outflow.

We obtained Hamilton coude'echelograms of Comet P/Brorsen-Metcalf at high spectral resolution on 1989 August 21 and 22 using the Lick 3-m reflector. Initial reduction analysis has been focussed on attempting to physically identify the carrier(s) of two here-to-fore unknown emission bands at $\lambda\lambda$ 4838 and 4510 Å. Both spectral features are spatially very concentrated to the cometary nucleus in all spatially resolved cometary spectra. They could be parent molecules or daughters of a species with a short dissociation lifetime. In fact, with the help of Dr. S. Tegler, we find the 4510 band to be a previously unrecognized NH_2 band, but the stronger features near 4838 Å remain unaccounted for. They are not due to CO, and probably not HCO.

c. Anticipated Accomplishments: Analysis of the P/B-M spectra and images will continue; as we write this the excitement over the opportunity to study a probable bright1 new comet [Austin] is growing. We have been assigned both spectroscopic and imaging time at Lick Observatory in May. We hope to observe the optical spectrum at $\Delta\lambda = 0.12$Å completely ($\lambda\lambda$ 4000 – 9000). A new cometary spectral atlas should result; of course we intend to try specific research goals [such as a new look at the $^{12}C/^{13}C$ ratio], from the echellograms, also.

The Evolution of Young Stellar Objects Disks And Their Environment

Five Colleges, Inc.

Stephen E. Strom

Excess infrared radiation above photospheric levels has been used to diagnose the presence of circumstellar dust disks surrounding solar-type pre-main sequence (PMS) stars, and to determine the evolutionary timescales for these disks. Our analysis of these objects combines published optical photometry, near-infrared fluxes, and IRAS fluxes for solar-type PMS stars in Taurus-Auriga, with new, highly sensitive 10μ measurements made with the NASA Infrared Telescope Facility (IRTF). Of our sample stars with ages, t<3Myr, ~ 1/2 show excess 3.5μ and 10μm emission consistent with that expected from optically thick disks of mass comparable to or greater than that of a minimum mass solar nebula, M_{min}. Although the total population of solar-type PMS stars in Taurus-Auriga is incompletely known at present, our result suggests that a significant fraction of solar-type PMS stars are surrounded by disks which are in principle capable of building planets. By an age t~10 Myr, fewer than 10% of our sample show evidence of dust emission from optically thick disks, and hence must have accreted or destroyed their disks, or have begun to assemble distributed gas and dust into larger bodies. Hence, the timescale over which disk survive as infrared-luminous, optically thick structures with a mass in distributed material is $\sim M_{min}$ is t<10Myr. Of that portion of our sample of solar-type PMS stars (average age, t~3 Myr) showing the infrared signatures of optically thick disks, approximately 10% show evidence on inner holes. These holes are signified by small near-IR $\lambda \leq$ 25μm excesses arising in optically thin regions located at r<0.2 AU, and large far-IR excesses produced in regions r>1 AU. Disks with inner holes are interpreted as "transition structures" which may have begun to assemble material into larger bodies in the terrestrial planet region. From the observed number of transition structures, the timescale for a given disk to evolve from a massive, optically thick disk to an optically thin structure is estimated to be t~0.3 Myr.

Recent high precision infrared observations provide clear evidence of excess emission arising in disks which are optically thin at r<1 AU. These observations appear to demand that disks be replenished with micron-size grains. The likeliest source of replenishment may be collisions among larger grains or planetesimals.

While infrared observations provide an indication of the dust content of circumstellar disk, there are at present few measurements of the disk gas content. We are currently using the Five College Radio Astronomy Observatory 14-m mm-wave antenna to carry out ^{12}CO (1-0) observations aimed at constraining timescales for gas survival in disks surrounding solar-type stars.

Asteroid Shapes and Pole Orientations From Visual and Infrared Photometry

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a. **Strategy:** 1. To obtain visual and infrared lightcurves of Pluto-Charon mutual eclipse event lightcurves and to analyze them to derive models of the Pluto-Charon system, including separations, relative sizes, some orbital parameters, system density, and an albedo map of the hemisphere of Pluto facing Charon. 2. To use these results in reducing Hubble Space Telescope observations to be obtained in February and/or July 1991 to determine the Pluto-Charon mass ratio. 3. To obtain visual and infrared photometry of selected asteroids to help determine their albedos, sizes, shapes, pole orientations, taxonomic classes, and phase functions.

b. **Accomplishments:** During 1989 observations of Pluto-Charon mutual events were obtained with the Palomar 5-meter and NASA IRTF 3-meter telescopes. Infrared lightcurves of the near-Earth asteroid 1580 Betulia were obtained on 3, 4, and 27 May 1989 UT. Papers on collaborative IRTF radiometry of near-Earth asteroids (Veeder *et al.*, 1988), the writing of seven chapters for the *Asteroids II* book, one chapter for the *Asteroids, Comets, Meteors III* book, a paper introducing a new asteroid taxonomy classification scheme, the publication of two Pluto newsletters (*Ninth Planet News* Nos. 7 and 8), and the organization and conducting of the fifth "Pluto Workshop" during the 1989 meeting of the Division for Planetary Sciences and the "Asteroid, Comet, Meteor Data Bases Workshop" at the Asteroids, Comets, Meteors III conference were supported by this grant.

c. **Anticipated Accomplishments:** During 1990 we will the final visual and infrared mutual event lightcurve observations, hold a sixth Pluto Workshop at the 1990 DPS meeting, and continue coordination of the international campaign and publication of the Pluto newsletter. We will complete reduction of all the visual data obtained to date and publish visual lightcurve data papers. Analyses of the IRTF and Palomar Pluto infrared data will be published. Next year we will publish an analysis of the visual data using a second-order eclipse model. Visual and infrared lightcurves of the near-Earth asteroid 1580 Betulia will be reduced, analyzed, and the results submitted for publication. Publication of a master data base of four decades of asteroid UBV photometry and a listing of asteroid absolute magnitudes and slope parameters which will be used in the 1992 *Ephemeris of Minor Planets* are planned.

d. Publications:

Gradie, J.C., Chapman, C.R., and Tedesco, E.F. (1989). Distribution of taxonomic classes and the compositional structure of the asteroid belt. In *Asteroids II* (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), pp. 316-335.

Matson, D.L., Veeder, G.J., Tedesco, E.F., and Lebofsky, L.A. (1989). The IRAS asteroid and comet survey. In *Asteroids II* (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), pp. 269-281.

Tedesco, E.F. (1989). Introduction to the asteroids II data base. In *Asteroids II* (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), pp. 997-1001.

Tedesco, E.F. (1989). Asteroid magnitudes, UBV colors, and IRAS albedos and diameters. In *Asteroids II* (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), pp. 1090-1138.

Tedesco, E.F. and Lindblad, B.A. (1989). Asteroid, Comet, Meteor Data Base Workshop Data Bases Workshop. In *Asteroids, Comets, Meteors III* (C.-I. Lagerkvist, H. Rickman, B.A. Lindblad, and M. Lindgren, eds.), pp. 605-608.

Tedesco, E.F., Matson, D.L., and Veeder, G.J. (1989). Classification of IRAS asteroids. In *Asteroids II* (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), pp. 290-297.

Tedesco, E.F., Williams, J.G., Matson, D.L., Veeder, G.J., Gradie, J.C., and Lebofsky, L.A. (1989). A three-parameter asteroid taxonomy. *Astron. J.* 97, 580-606.

Tedesco, E.F., Williams, J.G., Matson, D.L., Veeder, G.J., Gradie, J.C., and Lebofsky, L.A. (1989). Three-parameter asteroid taxonomy classifications. In *Asteroids II* (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), pp. 1151-1161.

Veeder, G.J., Hanner, M.S., Matson, D.L., Tedesco, E.F., Lebofsky, L.A., and Tokunaga, A.T. (1988). Radiometry of near-Earth asteroids. *Astron. J.* 97, 1211-1219.

Veeder, G.J., Tedesco, E.F., and Matson, D.L. (1989). Asteroid results from the IRAS survey. In *Asteroids II* (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), pp. 282-289.

Infrared Imaging of Comets

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This research focuses on the use of the 20-pixel bolometer spatial array developed at NASA-MSFC for a unique program of comet mapping with very high sensitivity in the wavelength range 8-30 μm. The array has been fully operational for about four years and has been used successfully at the Wyoming Infrared Observatory and, primarily, at the NASA Infrared Telescope Facility on Mauna Kea to map the comae and tails of numerous comets. In August 1985, this array was used to obtain the first thermal infrared images of a comet (Giacobini-Zinner at 10.8 μm) ever made from a groundbased observatory. We have also obtained IR images of comets Halley, Wilson, and Tempel 2. The 8-30 μm cometary emission originates in dust expelled from the nucleus and heated by sunlight. Dust can constitute a significant fraction of a comet's mass. Our imaging permits us to characterize many properties of the dust including the mass-loss rate, the particle size, the temporal development of the dust coma, and, with visual photographs, the distribution of the albedo. We have produced the first albedo maps ever made of comets.

Our accomplishments during FY1989 include the mapping of Comet Brorsen-Metcalf at 10 and 20 μm. Those results were presented at a conference in 1990 February in which we discussed the spatial variations in the albedo. Extensive analysis of the comets Wilson and Temple 2 were completed and published. In addition, progress was made on the development of two new cameras to be used in our comet research program.

This year we will complete the analysis of our Comet Brorson-Metcalf observations. A very high priority will be to obtain images of comets Austin and Enke in the Spring and Fall, respectively, at the NASA-IRTF. Finally, we hope to bring into full operation our InSb detector array for 1-5μm imaging and our ultrasensitive bolometer array for high-spatial-resolution mapping at 8-30 μm.

Campins, H., Lien, D.J., Decher, R., Telesco, C.M., and Clifton, K.S. "Infrared imaging of the Coma of Comet Wilson," 1989, Icaras, 80, 289.

Campins, H., Decher, R., Telesco, C.M., and Lien, D.J. "Groundbased Thermal IR Images of Comet Tempel 2," 1990, Icarus, in press.

Ridgeway, S.E., Jewitt, D., Campins, H., Luu, J., Joy, M., Sis, C., and Telesco, C.M. "An Albedo Map of Comet Brorsen-Metcalf," to be published in proceedings of the conference Astrophysics with Infrared Arrays, Tucson, 1990 February.

Planetary Optical and Infrared Imaging

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A. OBJECTIVES: The purpose of this investigation is to obtain and analyze high spatial resolution CCD coronagraphic images of extra-solar planetary material and solar system objects. These data will provide information on the distribution of planetary and proto-planetary material around nearby stars leading to a better understanding of the origin and evolution of the solar system. Tests of high efficiency coronagraph designs on ground-based telescopes will support the Circumstellar Imaging Telescope (CIT). Imaging within our solar system will provide information on the current cloud configurations on the outer planets, search for new objects around the outer planets, and provide direct support for Voyager, Galileo, and CRAF by imaging material around asteroids.

B. ACCOMPLISHMENTS: Over the last year this program acquired mulitspectral and polarization images of the disk of material around the nearby star Beta Pictoris and several other nearby objects. This material is believed to be associated with the formation of planets and provides a first look at a planetary system much younger than our own. An analysis of the Beta Pictoris color and polarization data suggest that the material is very low albedo and similar to dark outer solar system carbon rich material. A coronagraphic search for other systems is underway and has already examined over 120 nearby stars. An imaging processing data system has been set up to evaluate these data and to establish limits for circumstellar material. Coronagraphic imaging has provided the first clear look at the rings of Uranus and albedo limits for the ring arcs around Neptune.

C. PROPOSED RESEARCH: A survey of the nearby stars will be continued and data will be examined more deeply to provide limits on the probability of circumstellar material around stars and to understand the morphology of young planetary systems. Tests will be made of components of a higher efficiency coronagraph on ground-based telescopes using graded occulting masks. Further analysis of the Beta Pictoris polarization data as a function of color will be used to model the disk particle properties. These data will allow a measurement of the particle size distribution of dust in the disk. Coronagraphic imaging of the outer planets, asteroids and star forming regions will continue to provide support for ongoing missions such as Voyager, Galileo, CRAF, Cassini and CIT.

D. SUMMARY BIBLIOGRAPHY: 2 Papers and 1 abstract published.

Studies of Triton and the Pluto-Charon System

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Between late 1984 and late 1990, the orbit of Pluto's satellite Charon is aligned such that as seen from Earth a series of mutual transits, occultations, and eclipses occur. Photometric measurements of these events can be utilized to determine a variety of physical parameters, including the orbital elements of Charon, the sizes of the two objects, the mean density of the system, the individual reflectance spectra and surface compositions, and low spatial resolution albedo maps of one hemisphere on each body.

Through 1989, over 50 of these events have been observed from Mauna Kea Observatory. Several thousand individual observations have been acquired, typically at time intervals of 1 minute, with an average precision of 0.006 magnitudes. Sophisticated models have been fit to these data using the NSF-sponsored supercomputer facilities of the San Diego Supercomputer Center. Fitted values for the radii are 1150 km for Pluto and 593 km for Charon. Coupled with the system mass, these radii imply a mean density of 2.03 gm/cm^3, indicating a substantially rockier bulk composition than previously expected. The reflectance spectrum of Charon is quite neutral in color, which is in contrast to the reddish color of Pluto. The mapping efforts have shown Pluto to sport bright frost caps over each pole. The orbital period of Charon has been shown to match the rotational period of Pluto to a high degree of accuracy, indicating that the Pluto-Charon system has completely tidally evolved.

1990 is the last year of events. Only grazing geometry will occur during the opposition, but observations of these events are important because they will provide an independent determination of the albedo of the south polar cap, will help determine the extent of limb darkening effects, will provide radius measurements of Pluto and Charon orthogonal to the measurements made during the central events of 1987 and 1988 (which were derived from the duration of the events), and will help to further decouple certain partially correlated orbital elements.

Triton comes closer to resembling Pluto than any other solar system object in many respects. Ground-based observations of Triton in 1989 were intended to support the *Voyager 2* flyby of the Neptune system. These observations showed Triton to have a much more neutral color in 1989 than it did a decade earlier, indicating that temporal changes have taken place on Triton. Analysis of the photometric data is continuing in 1990 to extract the small-angle portion of the phase function and the rotational variation; the phase function will complement the large-angle *Voyager* coverage, and the rotational variation can be combined with the spacecraft data to provide an independent check and additional instrument calibration.

Visible and Infrared Investigations of Planet-Crossing Asteroids And Outer Solar System Objects

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The larger asteroids in the main belt have been fairly thoroughly studied by a variety of techniques. This project concentrates on the more poorly surveyed populations that are not contained in the main belt, namely the planet crossing asteroids of the Aten, Apollo, and Amor variety, the distant Hilda and Trojan populations, and unique objects like 2060 Chiron.

Observations of Chiron made in the early part of the 1980s showed a puzzling inconsistency that could best be explained by some sort of irregular brightness behavior. Repeated observations made specifically to look for such an irregularity came up negative until early 1988, when a doubling of the normal brightness of Chiron was seen. Observations are continuing to be made in collaboration with D. P. Cruikshank and W. K. Hartmann to characterize the nature of this outburst, and to compare it with the more extreme but short-lived outbursts of comet P/Schwassmann-Wachmann 1. We hope to address questions such as what volatile or volatiles are driving these outbursts at such great heliocentric distances, plus the particle sizes in the coma and their composition.

The rotational properties of Trojan and Hilda asteroids are being examined in collaboration with W. K. Hartmann to compare the collisional evolution of these relatively isolated populations with the more densely populated main belt. To date, about a dozen and a half objects have been observed with the surprising result that the average lightcurve amplitude is significantly greater among the Trojans (and possibly the Hildas, though this result is less certain) than in the main belt. More recently, we have hypothesized that some of these extreme shapes are in fact not due to collisional processes, but rather are the result of volatile loss processes acting over the lifetime of the object.

Newly discovered Earth-approaching asteroids are routinely observed both astrometrically, to help improve the determination of their orbits, and photometrically, to measure their rotation rates, shapes, and reflectance spectra, thereby providing information regarding their surface composition. Of the more exciting recent discoveries are the rare V-type surfaces found on 3908 1980 PA and 4055 1985 DO2. Radiometry of the latter indicates a diameter of 3 km, thereby establishing a lower limit on the thickness of the basaltic crust of the parent body.

Apollo and Aten asteroids also have a unique property in that they can be found between the Sun and the Earth, thus providing us with an opportunity to measure the thermal emission from their unilluminated hemisphere. Such observations provide an opportunity to much better constrain their surface roughness, sense of rotation, and thermal inertia than their main-belt counterparts. Since this part of the project was started, one Apollo asteroid, 4197 1982 TA, has provided the necessary geometry, and successful thermal observations were acquired at three widely separated phase angles. Analysis of these data are currently underway.

List of publications, alphabetical by first author's surname.

Beletic, J. W., R. M. Goody, and D. J. Tholen 1989. Orbital elements of Charon from speckle interferometry. *Icarus* **79,** 38-46.

Buie, M. W., and D. J. Tholen 1989. The surface albedo distribution of Pluto. *Icarus* **79,** 23-37.

French, L. M., F. Vilas, W. K. Hartmann, and D. J. Tholen 1989. Distant asteroids and Chiron. In *Asteroids II* (R. P. Binzel, T. Gehrels, and M. S. Matthews, Eds.), pp. 468-486. Univ. of Arizona Press, Tucson.

Harris, A. W., J. W. Young, L. Contreiras, T. Dockweiler, L. Belkora, H. Salo, W. D. Harris, M. Poutanen, R. P. Binzel, D. J. Tholen, and S. Wang 1989. Phase relations of high albedo asteroids: 44 Nysa and 64 Angelina. *Icarus* **81,** 365-374.

Hartmann, W. K., D. J. Tholen, K. J. Meech, and D. P. Cruikshank 1990. 2060 Chiron: Colorimetry and possible cometary behavior. *Icarus* **83,** 1-15.

Lark, N. L., H. B. Hammel, D. P. Cruikshank, D. J. Tholen, and M. A. Rigler 1989. The brightness and light curve of Triton in 1987. *Icarus* **79,** 15-22.

McFadden, L.-A., D. J. Tholen, and G. J. Veeder 1989. Physical properties of near-earth asteroids. In *Asteroids II* (R. P. Binzel, T. Gehrels, and M. S. Matthews, Eds.), pp. 442-467. Univ. of Arizona Press, Tucson.

Tholen, D. J., and A. Barruci 1989. Asteroid taxonomy. In *Asteroids II* (R. P. Binzel, T. Gehrels, and M. S. Matthews, Eds.), pp. 298-315. Univ. of Arizona Press, Tucson.

Astrometry for minor planets and/or comets have been published by D. J. Tholen in the following *Minor Planet Circulars*:

MPC 15967 (1990)	MPC 15324 (1989)	MPC 14725 (1989)
MPC 15948 (1990)	MPC 15174 (1989)	MPC 14552 (1989)
MPC 15810 (1990)	MPC 14992 (1989)	MPC 14124 (1989)
MPC 15325 (1989)	MPC 14847 (1989)	

Planetary Fabry-Perot Spectroscopy

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a. Earth based Fabry-Perot observations of planetary phenomena, including: High spectral resolution spectroscopy of planetary atmospheres, for which current topics are outer planet HD and H2 spectra (atmospheric structure, D/H ratio), Venus H2O and HDO. Associated laboratory spectroscopy (overtone bands of H2, HDO). Monochromatic CCD imaging photometry of the Jovian nebula, with images taken in sequence among the diagnostic spectral lines of ionized sulfur species, providing self calibrating snapshots of the Jupiter/Io plasma conditions (spatially resolved electron and ion densities and temperatures), covering the post-Voyager period from 1981 and leading up to the Galileo tour in the early 1990s. Spectral imaging of Io's neutral species (probe of Io's atmosphere through velocity structure in ion-neutral collision products). High spectral resolution Fabry-Perot spectroscopy of comets (OD/OH ratio).

b. Observations of the Jovian plasma torus and velocity resolved images of Io neutrals (focused on plasma interactions with the Io atmosphere) were carried out in Nov-Dec 1988, at the Mt. Bigelow (60 inch) observatory, in collaboration with N. Schneider (U. Arizona), including imaging simultaneously with spectroscopy of F. Roesler and students (U. Wisconsin) as part of Jupiter Watch 1988. Analysis of existing data and development of data reduction techniques has progressed. Models of the Io neutral velocity structure have been developed, allowing sampling in the manner of three dimensional Doppler resolved image sets (ie. x,y,dz/dt), in collaboration with H. Garrett. Systematic reductions of existing (1981-1988) Jupiter/Io plasma data are under way with Caltech graduate student K. Stapelfeldt. Laboratory spectroscopy of H2 overtone bands at high spectral resolution is scheduled for June 1989, to investigate line positions, pressure shifts, and intrinsic line strengths in support of existing planetary data, with M. Mickelson (Denison U.).

c. Completion of several papers (outer planet HD/H2, outer planet H2 profiles, Io atmosphere collision processes, Jovian nebula evolution and characteristics).

d. none.

Physical Properties of Asteroids

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a. Strategy: Infrared photometry at 1.2, 1.6 and 2.2 microns provides a relatively rapid and accurate method for the classification of asteroids and is important for comparison with laboratory measurements of meteorites and other possible compositional analogues. Extension beyond the visual is especially useful for minerals which have strong characteristic infrared colors such as olivine in the A class asteroids . Radiometry at longer infrared wavelengths, e.g. 10 microns, is important for deriving basic physical parameters via thermal models such as size and albedo which in turn enables the conversion of relative colors to absolute reflectances. In particular, albedos are the only way to distinguish among the otherwise ambiguous E, M and P classes of asteroids.

b. Progress: We obtained JHK and/or N infrared observations of 16 asteroids at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea during 1989. We have published an analysis of 22 Aten, Apollo and Amor asteroids. Our results include albedos and diameters for these objects as well as the identification of the first known class M and class E near-Earth asteroids. The "standard" thermal model appears to be inadequate for some of these small asteroids because of their coarse regolith so we have therefore constructed a rotating thermal model for such asteroids. We have identified several anomalous IRAS asteroids. Preliminary JHK results for the Eos family indicate that its members have relatively similar infrared colors.

c. Anticipated Accomplishments: We are now reducing JHK photometry from our survey of the main belt. We will initiate JHK observations of the Koronis family which will allow us to begin a direct comparison of the major asteroid families. We will continue to investigate selected unusual IRAS asteroids at 10 microns in order to characterize these interesting objects. We will exploit the new sub-micron facility at the IRTF by developing the capablity to derive accurate visual/infrared colors. SUMP will allow us to eliminate uncertainties due to large lightcurve variations of irregular near-Earth asteroids. SUMP will also permit us to refine our thermal models in order to investigate a possible metallic phase in the regolith of some asteroids.

d. Publications

Matson, D.L., Veeder, G.J., Tedesco, E.F., and Lebofsky, L.A. [1989]. The IRAS asteroid and comet survey. In Asteroids II, ed. R.P. Binzel, T. Gehrels and M.S. Matthews. [Tucson: University of Arizona Press], pp. 269-281.

McFadden, L.A., Tholen, D.J. and Veeder, G.J. [1989]. Physical properties of Aten, Apollo and Amor asteroids. In Asteroids II, ed. R.P. Binzel, T. Gehrels and M.S. Matthews. [Tucson: University of Arizona Press], pp. 442-467.

Tedesco, E.F., Matson, D.L. and Veeder, G.J. [1989]. Classification of IRAS asteroids. In Asteroids II, ed. R.P. Binzel, T. Gehrels and M.S. Matthews. [Tucson: University of Arizona Press], pp. 290-297.

Tedesco, E.F., Williams, J.G., Matson, D.L., Veeder, G.J., Gradie, J.C. and Lebofsky, L.A. [1989]. A three-parameter asteroid taxonomy. *Astron. J.*, **97**, 580-606.

Veeder, G.J., Hanner, M.S., Matson, D.L., Tedesco, E.F., Lebofsky, L.A. and Tokunaga, A.T. [1989]. Radiometry of near-Earth asteroids. *Astron. J.*, **97**, 1211-1219.

Veeder, G.J., Tedesco, E.F., and Matson, D.L. [1989]. Asteroid results from the IRAS survey. In Asteroids II, ed. R.P. Binzel, T. Gehrels and M.S. Matthews. [Tucson: University of Arizona Press], pp. 282-289.

Astrometric Observations of Comets and Minor Planets

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a) Objectives: Comets and asteroids are observed with the Palomar 1.5m telescope using a CCD array. The goal is observations of astrometric quality (the reduction to positions is separately funded) and priorities are comets plus minor planets which are planet crossers, Trojans, Hildas, have high inclinations, or otherwise have unusual orbits. The stress is on recoveries of comets and asteroids seen at previous oppositions and follow up on newly discovered objects. Surveys and new discoveries are not being attempted. The modest amount of available dark time is used for faint objects, while brighter objects can be followed in the more plentiful light time. Since asteroids are usually discovered near perihelion when bright, the next several opportunities for recovery are normally fainter. Thus big telescopes complement discoveries by smaller instruments.

b) Progress: During the past year eight periodic comets were recovered. They were P/Du Toit-Neujmin-Delporte (19891), P/Gehrels 2 (1989n), P/Wild 2 (1989t), P/Kearns-Kwee (1989u), P/Tuttle-Giacobini-Kresak (1989b1), P/Schwassmann-Wachmann 3 (1989dl), P/Russell 4 (1989gl), and P/Van Biesbroeck (1989hl). The 1989dl recovery was shared. Recoveries of planet crossing asteroids include 1987 QA, 1987 UA, and 1989 FB. A variety of additional comets and interesting asteroids, including more than two dozen planet crossers, were also recorded.

c) Proposed Research: The CCD observing program on the 1.5m Palomar telescope will be continued for the recovery of faint comets and minor planets. The priorities will emphasize first opposition follow up and second opposition recovery. Comets and planet crossing and other unusual asteroids will be given priority. This is not a survey program.

d) Publications: The comet recoveries were presented on eight IAU cards. One abstract was published.

Cometary Spectroscopy

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Strategy- Observations of NH_2, [OI], CH, CO^+, CO_2^+, H_2O^+, and N_2^+ in optical spectra of comets represent ionization and dissociation products of virtually all of the volatile fraction of a comet nucleus, and can provide abundances of N_2, NH_3, H_2O, CH_4, CO_2 and CO. The primary objectives are to determine: 1) accurate production rates for the observed species, and 2) accurate relative abundances of condensates in a sample of comet nuclei. The ultimate goal is to constrain models of comet formation and chemical processing in the outer primordial solar nebula.

Accomplishments- An intercomparison of Monte Carlo, vectorial and Haser models applied to surface brightness profiles of NH_2 demonstrated for the first time that ammonia production rates can be determined from the NH_2 spectrum with only small differences between the models. As part of his dissertation, Tegler showed that the parent of NH_2 must be a species with a photodissociation lifetime $\lesssim$8000 s. He concluded that NH_3 with a calculated photodissociation lifetime of 7700 s must be the dominant parent of NH_2, and that the ammonia/water ratio in comet Halley is 0.2 %. Moreover, we have found that the mean ammonia/water abundance ratio in four comets is $0.13\pm0.06\%$, with no significant variation among the comets. The uniformity of the ammonia abundances among the four comets attests to a remarkable degree of chemical homogeneity over large scales (>1AU) in the comet forming region of the primordial solar nebula, and contrasts with the CO abundance variations found previously in comets by Feldman and his colleagues.

In Progress- A multi-step, time-dependent Monte Carlo model of a comet coma is being developed with A. Ferro to apply to observed radicals which have more than one parent or a multi-generational history such as methane and ammonia products. With L. Engel calculations of photodissociation and photoionization rates are being carried out using a relatively high resolution solar EUV spectrum to account for the predissociation structure in the molecular cross sections. Photodissociation of molecules such as H_2O and N_2 which are particularly sensitive to the Swings effect and solar EUV flux variations are being investigated. Abundances and the structure of the comet ionosphere are being studied both spectroscopically and with narrow-band images. The N_2^+, CO^+, CO_2^+, OH^+, CH^+ and H_2O^+ spectra are being analyzed in several comets. The N_2^+/CO^+ ratio is being used to derive N_2/CO abundance ratios in comets. In collaboration with R. Wegmann and H. Schmidt a three-dimensional MHD model of the ionosphere is being used to investigate ion velocity measurements of comet Halley. Images isolating the H_2O^+ (8-0) emission band have been obtained of the ionosphere of comet Brorsen-Metcalf. Both spectroscopic and narrow-band images of comet Austin will be obtained in May and June with telescopes in both the northern and southern hemispheres.

Relevant Publications in or Submitted to Refereed Journals
(1989 July - 1990 March)

1. Tegler, S. and Wyckoff, S.: Fluorescence Efficiencies of NH_2. *Ap. J.*, **343**, 445-454, 1989.
2. Wyckoff, S., Tegler, S. and Engel, L.: Ammonia Abundances in Comets. *Adv. Space Res.*, **9**, 169-173, 1989.
3. Wyckoff, S. and Lindholm, E.: On the Carbon and Nitrogen Isotope Abundance Ratios in Comet Halley. *Adv. Space Res.*, **9**, 151-154, 1989.
4. Wyckoff, S. and Theobald, J.: Molecular Ions in Comets. *Adv. Space Res.*, **9**, 157-168, 1989.
5. Konno, I. and Wyckoff, S.: Atomic and Molecular Abundances in Comet P/Giacobini-Zinner. *Adv. Space Res.*, **9**, 122-139, 1989.
6. Wyckoff, S. Lindholm, E., Wehinger, P. A., Peterson, B., Zucconi, J-M., and Festou, M.: The $^{12}C/^{13}C$ Abundance Ratio in Comet Halley. *Ap. J.*, **327**, 542-555, 1989.
7. Wyckoff, S. and Lindholm, E.: On the Carbon and Nitrogen Isotope Abundances in Comet Halley. *Astron. J.*, in press, 1989.
8. Lindholm, E. and Wyckoff, S.: Measurement of the Plasma Acceleration in Comet Halley. *Ap. J.*, in press, 1989.
9. Wyckoff, S.: Plasma Environments of Comets. J. Geophys. Res., im press, 1990.
10. Konno, I. and Wyckoff, S.: Observations of comet P/Giacobini-Zinner Before, During and After the ICE Spacecraft Encounter. *Ap. J.*, in press, 1990.
11. Konno, I. and Wyckoff, S.: Abundances in comet P/Giacobini-Zinner using a Monte Carlo Model. *Ap. J.*, in press, 1990.
12. Wyckoff, S.: Cometary Clues to the Origin of the Solar System. *Earth Sci. Reviews*, in press, 1990.

Comet and Asteroid Dynamics

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a.) Strategy: In order to provide observers with accurate ephemerides of comets and asteroids, up-to-date astrometric positions must be used to improve the existing orbits. For active comets, nongravitational forces must be taken into account; these forces are assumed due to the rocket-like effect of outgassing cometary ices and are used to infer the characteristics of icy cometary nuclei. In an effort to improve ephemeris accuracies, a new nongravitational force model for comets is being used and radar Doppler and range measurements are being employed as astrometric data types.

b.) Accomplishments: The recently developed nongravitational force model for active comets was published in the open literature. The new model allows cometary outgassing to reach a maximum on either side of perihelion and the optimum offset of this modeled outgassing maximum usually corresponds to the comet's observed brightness maximum. Together with the water production rates available for comet Halley, the new model was used to estimate the mass and density of comet Halley's nucleus (approximately 5 x 10^{17} g. and 1 g/cc). Using this new model, a much improved orbit for comet Brorsen-Metcalf was computed. This comet arrived at perihelion nearly 16 days ahead of predictions - a result of the comet's preferential outgassing pre-perihelion and its relatively small size (it's radius is about 4 times smaller than comet Halley's). Orbits and radar ephemeris predictions facilitated the first successful radar detections of asteroids 1580 Betulia, 1917 Cuyo, 1989JA, and 1989PB. For the latter two close Earth approaching asteroids, radar data from Arecibo was used to update the ephemeris predictions for the subsequent Goldstone observations - a first for asteroid orbit determination. During 1989-1990, radar ephemeris predictions were also provided for Mercury, Venus, Saturn, and Titan. Accurate ephemeris information on approximately two dozen comets and asteroids were provided to users both outside and within the NASA community.

c.) Anticipated Accomplishments: As a service to those who do comet and asteroid orbit determinations, the procedures will be outlined for switching from the currently used B1950 coordinate system to the more accurate J2000 system. The procedures necessary to process astrometric radar data for comets and asteroids will also be prepared for publication. Additional "radar" orbits for close Earth approaching asteroids will be determined and accurate comet and asteroid ephemerides will be provided to the observing community.

d. Publications

Ostro, S.J., Yeomans, D.K., Chodas, P.W., Goldstein, R.M., Jurgens, R.F. and Thompson, T.W. (1989). "Radar Observations of Asteroid 1986 JK", Icarus, 78:382-394.

Ostro, S.J., Jurgens, R.F., Yeomans, D.K., Standish, E.M., and Greiner, W. (1989). "Radar Observations of Phobos", Science, 243:1584-1586.

Yeomans, D.K. and Chodas, P.W. (1989). "An Asymmetric Outgassing Model for Cometary Nongravitational Accelerations", Astronomical Journal, 98:1083-1093.

"Observations of the 8 December 1987 Occultation of AG+40°0783 by 324 Bamberga", (1989). Astronomical Journal, 98:1094-1099. (19 co-authors).

HIGHLIGHTS
OF
RECENT ACCOMPLISHMENTS
IN
PLANETARY ASTRONOMY

An Advance in the Determination of the Spin Period of P/Halley .... M.J.S. Belton

An independent analysis of VEGA/Giotto imaging data by Michael Belton has shown that a precession period for the long axis of 3.7 days will account for the observations. A comparison of this result with a new analysis of ground-based time series photometry indicates that the spin period of Halley can now be restricted to the consideration of three possible states. A SAM (short axis mode) or LAM (large axis mode) rotator with a precession period of 3.7 days and a "nodding" period of 7.4 days; or a LAM with the same precession period but a nodding period of 2.5 days. This work has been accepted for publication in Icarus. Research is ongoing to differentiate between these models.

An Atmosphere Detected Around Chiron .... M.J.S. Belton

In April, 1989, as part of a program of P/Halley observations, K. Meech and Michael J.S. Belton obtained CCD images of 2060 Chiron, which showed an extended coma. Apparently Chiron is a comet rather than an asteroid. The coma is distinct from that found in normal comets in that it's surface brightness falls off with distance from the nucleus at a much greater rate. Meech and Belton have constructed a theory of Chiron's atmosphere as a dynamic accumulation of gravitationally bound dust particles in "satellite" orbits about the nucleus. There is apparently little gas in Chiron's atmosphere. This work has been submitted to the Astronomical Journal for publication.

What Causes Disconnection Events? .... J.C. Brandt

Perhaps the most spectacular event in cometary plasma physics is the regular loss of the entire plasma tail and the growth of a new one. This is called a disconnection event or DE.

Understanding the cause of DEs would be a most important step in our knowledge of cometary plasmas and the interaction with the solar wind. We are assembling detailed information on many DEs; some 20 obvious DEs were recorded for Halley's Comet in 1985/1986.

The analysis for the DE of 10 January 1986 is complete. The event shows a very close correspondence to the comet's crossing of the heliospheric current sheet (sector boundary) and strongly supports mechanisms based on reversal of the solar-wind magnetic field impinging on the comet. When the analysis is completed for additional events, we should have an excellent idea of the cause of DEs.

Triton's Surface and Atmosphere .... D.P. Cruikshank

Dale P. Cruikshank, R. H. Brown, L. P. Giver, A. T. Tokunaga

Triton is Neptune's largest satellite, and while its intrinsic brightness has long suggested that it is sufficiently large to retain an atmosphere, only in the last decade has it become possible to make spectroscopic observations in the near-infrared where diagnostic bands of expected gases and ices occur. Voyager has now flown through the Neptune-Triton system, giving a close-up view of the nature of Triton's surface and vital information on the density and temperature of the atmosphere, the surface temperature, and the satellite's bulk density. However, before the Voyager encounter occurred, telescopic work from Earth gave some crucial information on both the surface composition and the existence of an atmosphere (see **Science 245**, 283, 1989).

In 1977, Cruikshank and Silvaggio found the 4350-cm^{-1} (2.3-μm) methane band in the spectrum of Triton and deduced that an atmosphere and surface ice deposits must be present. Methane ice and gas both exhibit the 4350-cm^{-1} band and are indistinguishable from one another in spectra with resolution poorer than 30 cm^{-1}. Seven individual methane bands in the range 3.5 μm) have now been observed in the IR spectrum of Triton. In addition, a band at 4650 cm^{-1} (2.15 μm) attributed to the (2-0) density-induced band of molecular nitrogen was identified by us in collaboration with R. N. Clark. From absorption coefficients of this band (measured in liquid nitrogen), Cruikshank et al. deduced that the quantity of N_2 needed on Triton to form this band exceeds that which could exist as a gas, and therefore N_2 must occur in a condensed state on the surface. They further concluded that the 4650-cm^{-1} band was produced in the upper several cm of a liquid layer as seen through a transparent atmosphere. We now know that the nitrogen on Triton is frozen because of the very low surface temperature of about 40K, but prior to the Voyager encounter, the temperature of the surface, hence the state of the nitrogen, was not known.

The telescopic work on Triton has shown that not only do methane and ammonia exist on the surface and (by vapor pressure considerations) in the atmosphere, but that the satellite's spectrum changed significantly sometime in the early 1980s. Furthermore, the uniformity of the rotational lightcurve, which is sensitive to nonuniform distribution of materials of contrasting albedo on the surface or in the atmosphere, as observed in 1988, indicated that changes had occurred in the atmosphere or on the surface in the decade of the 1980s.

The telescopic observations and analysis predicted the presence of an atmospheric haze on Triton, but predicted that the haze would be quite transparent at optical wavelengths. From the ground-based data, we predicted that Voyager spacecraft cameras would see the surface with no difficulty at small observing angles, and would detect the haze at the satellite's limbs, both of which predictions were borne out during the Voyager flyby in August, 1989. Furthermore, Voyager observations of the color of the surface are consistent with an overall change in the optical properties of the uppermost surface layer in the 1980s.

Three Basaltic Earth-Crossing Asteroids and the Source of the Basaltic Meteorites .... D.P. Cruikshank

Dale P. Cruikshank, D. J. Tholen, W. K., Hartmann, J. B. Bell, and R. H. Brown

Continuing telescopic investigations of Earth-approaching asteroids by our group has revealed the basaltic composition of three interesting bodies. In our paper, recently submitted to **Icarus**, we report five-color photometry, near-infrared spectra (0.8-2.5 μm), and thermal observations of the Earth-approaching asteroids (3551) 1983 RD, (3908) 1980 PA and (4055) 1985 DO2. We derive their diameters as 1.2 km, 1.0 km, and 3.4 km, respectively. Apart from greater absorption band depths, the spectra of these three small asteroids are nearly identical to that of Vesta, which is known to have a differentiated basaltic surface. The deeper pyroxene bands (0.9 and 1.9 μm) relative to Vesta, are consistent with more pyroxene-rich surfaces, larger mineral grain sizes in their optically immature regoliths, more bare rock surfaces, or all of these factors. These small Earth-approaching asteroids have similar orbits, with perihelia near Earth's orbit in July/August. They are probably not fragments of Vesta, but may be fragments of one or more Vesta-like parent bodies. The spectra of Vesta and the three Earth-approachers resemble those of the basaltic meteorites, i.e. eucrites, howardites, and diogenites (HED meteorites). We find that HED fall times show a weak peak in July/August, suggesting that 3551, 3908, and 4055 may be fragments of the source bodies of the HED meteorites, or perhaps of a single common HED parent body.

Our thermal infrared observations show that these kilometer-size asteroids have regoliths with significant insulating properties, but that these regoliths differ from that of the Moon in that the particles sizes are larger than on the Moon, and lunar-like glasses and agglutinates are largely absent. The causes of these differences are related to impact velocities, impact shaking, and debris retention on small bodies.

In calling attention to the fact that these three Earth-approaching asteroids have basaltic surfaces, we note that differentiated basalt or asteroids with mantle-like compositions may have impacted Earth and left discontinuities in the geologic/climatic record without leaving the chemical signatures associated with the K-T boundary event.

Surveying of the Solar System .... T. Gehrels

New techniques of surveying for comets and asteroids are being developed with charge-coupled devices on the "Spacewatch Telescope" which is dedicated during the dark half of each month for this work by the Steward Observatory on Kitt Peak. A parallel program is coming along at the Kavalur Observatory of the Indian Institute of Astrophysics. Our charge-coupled device (CCD) has 2048 x 2048 pixels, presently the largest in the world; it has a computer system, in the telescope dome, for automatic recognition and discovery of fast-moving objects such as comets and asteroids. We use the CCD in a scanning mode: the electronic signal charges are shifted incrementally from one row of CCD pixels to the next in a "bucket brigade" process, and this is done at a rate which is exactly the same as the rate at which the telescope scans the sky. This allows the CCD to be exposed and read out simultaneously and continuously for as long as the data collection system can store the accumulating scans. The scans of a certain area on the sky are repeated and superposed in the computer: objects that occur in the same position, such as stars and nebulae, are subtracted out, while the images that occur in different places in the consecutive scans are thereby discovered as belonging to moving objects. Our first near-Earth asteroid, 1989UP, was discovered with the 2048 x 2048 CCD. Its perihelion distance is 0.98 AU indicating that it is gravitationally controlled by the Earth and may eventually impact. Aphelion is in the middle of the asteroid belt where it probably originated, as a near-Earth asteroid, in a collision. Its mean diameter is about 0.3 km; that is in the lowest 10 percent of the sizes of near-Earth asteroids that are presently known. W. Wisniewski (personal communication, 1989) observed a lightcurve amplitude of more than a magnitude, so it is an elongated object, which appears to confirm that it is a fragment of a collision.

Palomar Planet-Crossing Asteroid Survey (PCAS)...E.F. Helin

The discoveries of the PCAS program during 1989/1990 have exceeded those of any prior year since its initiation. Eleven Near-Earth Asteroids, 6 Apollos and 5 Amors, were found. Of the 201 other asteroids discovered, 30 were unusual high inclination asteroids. Twenty-eight asteroids were recovered (reobserved during their second and third apparitions), permitting their permanent numbering. Five of these are Near-Earth Asteroids.

Five new comets, 3 short-period and 2 parabolic, were discovered along with the recovery of P/Brorsen-Metcalf. Considerable press coverage was given our Caltech SURF students' discovery of a new supernova while working with the PCAS program during the summer of 1989.

Apollo 1989 JA made one of the closer approaches to Earth during 1989. At about 8 million miles during the summer it was possible to acquire radar data (S. Ostro, JPL), significantly improving its orbit and thus assuring its future recovery. More exciting still, another Apollo 1989 PB, discovered by PCAS in early August was to come yet closer to Earth - about 2.1 million miles. Two dimensional radar images of the rotating asteroid were obtained over several nights showing a unusual "contact binary asteroid" - the probable result of a low velocity impact of two separate asteroids. Worldwide attention has been given these remarkable results showing the first "pictures" of an unusually shaped NEA (Ostro).

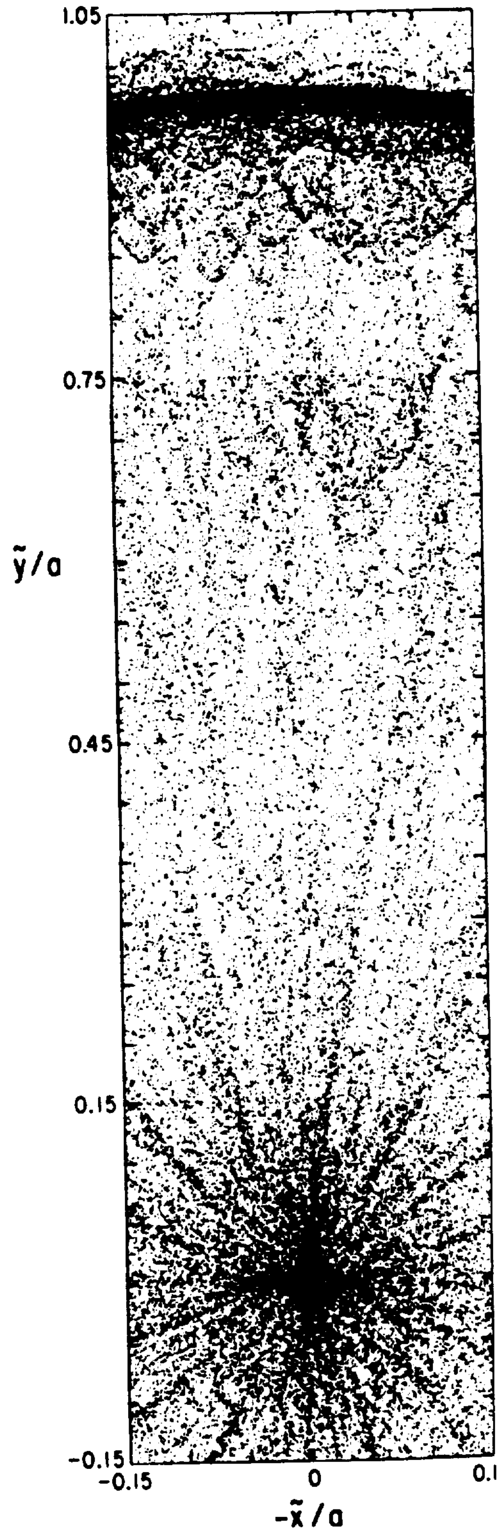
The Amor 1989ML is unusual, having the smallest semi-major axis of any known Amor. Its present orbit neither crosses the orbit of Mars or Earth, but with its relative close proximity to Earth, low inclination and low eccentricity, it appears to be an excellent mission candidate.

The 30 asteroids with high inclinations are predominantly Hungaria and Phocaea region objects, generally orbiting the sun just beyond Mars and thought to be the source of some of the Near-Earth Asteroids.

Comets, almost certainly a source of Near-Earth Asteroids, were discovered with unusual frequency during the year. Four were found within a seven week period. A bright, fast-moving object, Comet Helin-Roman, 1989s, was discovered on Labor Day, 4 September. It is a parabolic comet and was found at closest approach to the Earth at about 0.6 AU moving a rapid 2.2 degrees a day. The 3 periodic comets are probably relatively new in their present orbits, having occasional close encounters with Jupiter.

Neptune's Complex Occultation Shadow .... W.B. Hubbard

Coordinated earth-based observations of stellar occultations by Neptune over the past decade have revealed remarkable structure in the shadow cast by the planet in the starlight. Observations with very high signal/noise at 2 microns have succeeded in detecting the stellar flux throughout the shadow, including close to the center, where the light is brought to a partial focus by the entire atmosphere, and the signal probes layers at pressures of a few tenths of a millibar. The figure shows a computer reproduction of the qualitative structure of the shadow based on parameters inferred from recent Neptune occultations. The density of points is proportional to the stellar flux, and the figure shows a north-south view of the shadow plane, where the linear dimensions are measured in units of Neptune's equatorial radius *a*. The diamond-shaped central spot is made up of caustics (first detected in 1985) which reveal the planet's oblateness to be about 0.02. The radial streaks, which convert to "spikes" parallel to the limb near the edge of the shadow, may be produced by large-scale gravity waves in Neptune's stably stratified mesosphere. Near the edge of the shadow, where the rays penetrate to a pressure of about one microbar, the flux level indicates an atmospheric temperature of about 150 K. But near the center, with the rays probing to a pressure several hundred times higher, the flux level implies that the atmospheric temperature has declined to a value near 135 K.



Cometary Activity in 2060 Chiron .... D.C. Jewitt

The development of cometary activity in 2060 Chiron has been closely monitored using a variety of facilities at the Mauna Kea and Kitt Peak Observatories (Fig. 1). The distinguishing characteristics of activity in Chiron at heliocentric distance R ~ 11 - 12 AU are

(1) the long duration of the recent "outburst", which began late in 1987 and peaked in late 1988
(2) the non-asteroidal brightening is limited to ~ 1 mag.
(3) the surface brightness profile of the coma is steep and time-dependent
(4) the coma is the same color as the nucleus, with no evidence for Rayleigh scattering
(5) the coma is optically thin along the line of sight, as determined from the rate of diminution of lightcurve range (Fig. 2).

These and other characteristics may have a natural explanation in terms of the sublimation of a super-volatile material on Chiron. The leading candidate is CO, since this molecule was found in abundance in comet Halley. However, other materials, including N_2 and to a lesser extent CO_2, may drive part or all of the mass loss. Existence of supervolatiles in Chiron may be consistent with laboratory experiments which suggest that large masses of such gases can be trapped in amorphous ice during condensation at low temperatures.

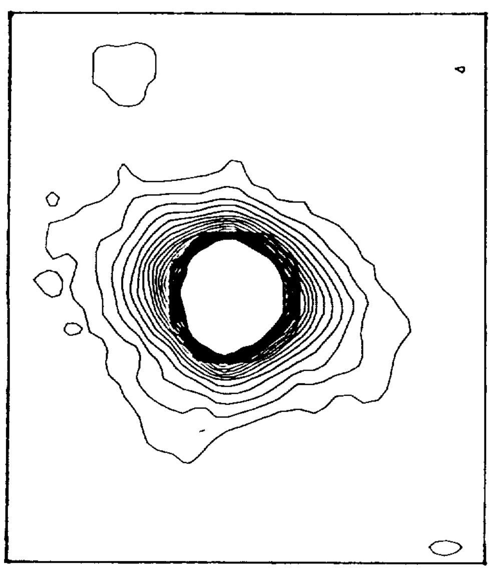


Figure 1. Contour plot of Chiron from a median image (effective integration time = 4500 s). North is to the right, West is to the bottom. The coma is clearly visible and extends at least 10" in the SE and NW directions.

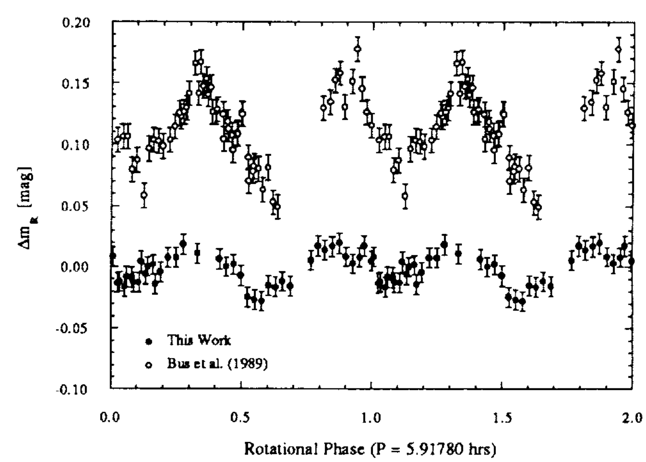


Figure 2. Rotational lightcurves of 2060 Chiron from 1986 (top, Bus *et al.* 1989) and from 1990 (bottom, Luu and Jewitt, *A. J.* 1990). The range in 1990 is diminished by dilution in an optically thin dust coma.

Arsenic in Jupiter and Saturn.................................... R.F. Knacke

K.S. Noll, R.F. Knacke, and T.R. Geballe recently discovered arsenic in the atmospheres of Jupiter and Saturn. This is the first time arsenic, which occurs in the molecule, arsine, AsH_3, has been observed in the outer solar system, and its discovery brings the number of known elements in Jupiter to only eight. The reactive and dangerous gas is a trace constituent, with less than one molecule of AsH_3 for a billion (10^9) molecules of hydrogen (H_2) in Jupiter. Although this is a trace amount, there is relatively (to hydrogen) more arsenic in Jupiter and Saturn than there is in the Sun. The over abundance is additional support for theories of giant planet formation in which refractory elements in dust and planetesimals accumulate first in a dense core, which is then surrounded later by a massive gaseous envelope.

Ethane on Neptune .... T. Kostiuk

Ethane mole fractions on Neptune were determined from infrared heterodyne spectroscopic measurements of the C_2H_6 RR (4,5) emission line at 840.9764 cm^{-1}. The measured line was fit using existing atmospheric models and C_2H_6 mixing ratio profiles for Neptune. Non-constant mixing ratio profiles derived from the photochemical model of Romani and Atreya (1989) were tested. Our results require 2.0 to 5.8 times more ethane in the 0.02 - 2 mbar pressure region than the photochemical model predicts. Ethane mole fractions ~3 x 10^{-6} were retrieved near the 0.27 mbar pressure level (line center contribution function peak) for all models tested. The cumulative uncertainty on the retrievals, excluding that associated with the temperature profile, is 30%. Better agreement with the model can be achieved if the eddy mixing is reduced in the lower stratosphere and/or the stratospheric temperature is increased by >10°K above the 6 mbar level.

T. Kostiuk, F. Espenak, P. Romani (SSAI), J. Goldstein (NASM),
D. Zipoy (U. MD)

Ethane and Ethylene Near the Poles of Jupiter .... T. Kostiuk

Measurements of individual emission lines of ethane and ethylene from the stratosphere of Jupiter were made at the NASA Infrared Telescope Facility in December 1989 using a dual laser infrared heterodyne spectrometer operating at 10.5 μm (ethylene) and 12 μm (ethane). The goal of the investigation was to study the spatial variability of the hydrocarbons on Jupiter and the behavior of the emissions in the north and south polar " Hot Spot" regions. Ethane was found to exhibit enhanced emission over a broad region around the north auroral zone of the planet. Ethylene emission increased at least ten-fold in a confined "Hot Spot" at 60 deg. north latitude, 180 deg. longitude (System III, 1965). This behavior is similar to that of methane and acetylene on Jupiter. Emission from both of these molecules was also found to increase at this north polar "Hot Spot". These measurements represent the first definitive ground based detection of ethylene on Jupiter, confirming our earlier results on the Jovian equatorial region. They also confirm the identification of ethylene in the Jovian "Hot Spot" by Kim et al. 1985 using Voyager IRIS data. Coordinated measurements of ethane within the south auroral zone on Jupiter were made simultaneously with observations of hydrogen quadrupole and H_3^+ emission near 2μm by Larry Trafton (U. Texas) at the McDonald Observatory. The goal was to correlate the emissions observed by the two sets of measurements (which probe different altitude regions of Jupiter's atmosphere) in an attempt to determine their origin and variability. Using these correlated results, along with analyses of the ethane and ethylene measurements and the previous results for methane and acetylene, we hope to gain insight into the unique phenomena occurring in the Jovian polar regions. Additional simultaneous measurements including the spectral regions near 10 μm, 12 μm, 2 μm, and UV (IUE) are being planned for the future.

T. Kostiuk, F. Espenak, P. Romani (SSAI), J. Goldstein (NASM)

Venus Atmospheric Dynamics

The Goddard infrared heterodyne spectrometer was used at the NASA Infrared Telescope Facility in January and February, 1990 to obtain absolute line-of-sight wind velocities in the lower thermosphere (100-120 km altitude) and the mesosphere (70-80 km altitude) of Venus. The velocities can be determined from the measured Doppler shifts of $^{12}C^{16}O_2$ thermospheric emission lines and $^{13}C^{16}O_2$ mesospheric absorption lines to several meters/sec. Such velocities will allow the first definitive determination of the mesospheric global wind field - including: the strength of zonal super-rotation, the detection of antisolar-to-subsolar return flow, and the detection of mid-latitude zonal jets (at the 5 m/s level). Our previous thermospheric measurements have detected ~120 m/s subsolar-to-antisolar flow and a 10-30 m/s equatorial retrograde zonal component (Goldstein et al. 1985; Goldstein, 1989, Ph. D. Thesis). Current thermospheric observations will yield near solar cycle maximum values for the subsolar-antisolar wind field and permit better determination (to few m/s) of the magnitude of the remnant super-rotation.

These observations are optimized when Venus is large (60 arcsec) and its limb illuminated, as it is near inferior conjunction. These observing runs were scheduled to yield results on opposite phases around inferior conjunction of Venus.

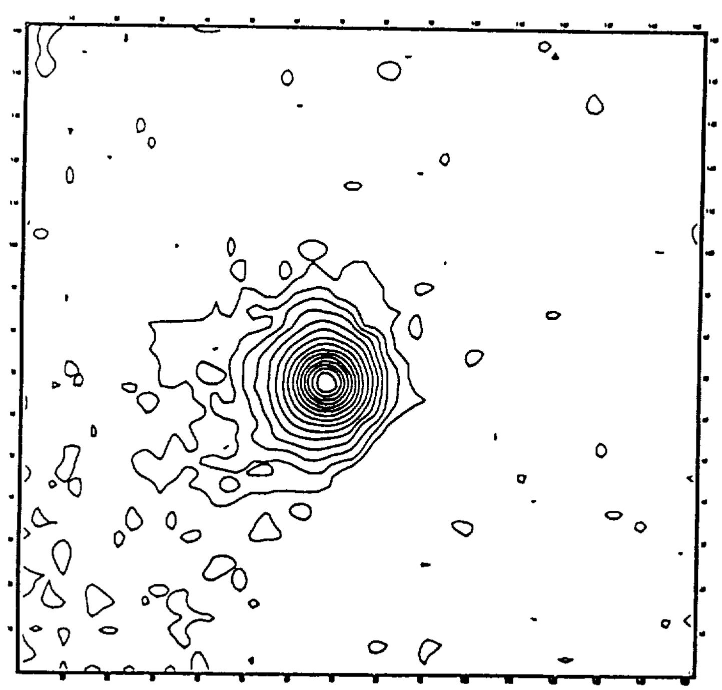
J. Goldstein (NASM), T. Kostiuk, M. J. Mumma, F. Espenak

The Ion Tails of Comets P/Brorsen-Metcalf and Okazaki-Levy-Rudenko .... S. Larson

With exceptionally low dust production from the bright comets P/Brorsen-Metcalf (1989o) and Okazaki-Levy-Rudenko (1989r), it was possible to obtain nearly contamination-free H_2O+ (619nm) CCD images with good spatial and temporal resolution. A 1.3 hour sequence of 18 images of 1989o was obtained with the Catalina 1.5 m telescope on 1989 August 23 UT which showed the evolution of ion structures from diffuse hoods of accumulated ions 10,000-17,000 km sunward from the nucleus, to quasi-symmetric rays which "fold" towards the tail axis with time. The apparent remnant tail of a "disconnection event" can be seen moving down the tail at 60 km/sec. The narrow tail axis can be traced to within 600km of the nucleus; apparently limited only by the resolution (300km/px). Shorter sequences of 1989o on August 24, and of 1989r on November 22 show similar features. Detailed analysis is underway, but these observations seem qualitatively consistent with Alfen's magnetic field draping model. These data indicate that at 100km resolution, ion structure motions near the nucleus can be detected in less than one minute. The left-hand image is a 300 sec. exposure of 1989o on 1989 Aug. 23.4872 UT showing a strong H_2O+ central tail and two folding rays. The length of the star trail is 16,660 km long at the comet. The other image (same scale and orientation) is the difference of two superimposed 120 sec. exposures taken 300 sec apart on Aug. 23.506 UT. Any structure in the image is due to motion between the two exposures. The outer diffuse hood later formed folding rays similar to those seen defining the edge of the ion tail. The folding rays seen in the left-hand image have rotated towards the tail axis to form the edges of the bright central tail core in the right-hand image.

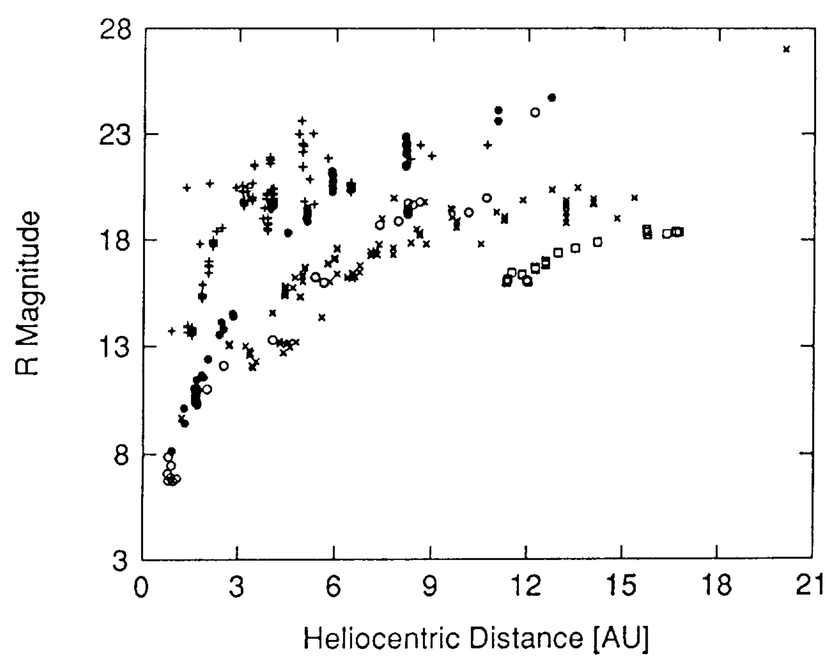
Activity on 2060 Chiron.. K.J. Meech

Observations of Chiron from various investigators since 1987 have shown that it has been brightening much more rapidly than expected for an inert asteroidal body. Although it was widely believed that this brightening was due to some sort of cometary activity, there was no direct evidence of any coma until 1989 April. At this time the first evidence of a low surface brightness coma was observed with the Kitt Peak 4m telescope (Meech and Belton, (1989), *IAU Circ. 4770*). A contour plot of the coma seen on 1989 Dec. 27 with the Canada-France-Hawaii Telescope is shown in the figure below, where the contours increase from the lowest level at 24.8 mag / arcsec^2 in increments of 0.5 mag. The coma extends to the southeast in approximately the same direction as the projected anti-solar radius vector. This faint imaged coma probably represents small sub-micron particles which have been able to achieve escape velocity from the nucleus. Because of the large nuclear size (approximately 180 km in diameter), the majority of the particles which are entrained in the gas flow (most likely CO) from Chiron are unable to achieve escape velocity and become gravitationally bound within a region roughly 5000 km in extent which lies between the surface and an exopause imposed by radiation pressure forces.



Differences Between Dynamically New and Periodic Comets .... K.J. Meech

The large data base of photometric observations of the central 5 arcsec of the nucleus and comae of periodic and dynamically new comets as a function of heliocentric distance is indicating that there is a substantial difference in the amount of activity between the two classes. With the exception of P/Halley, all of the periodic comets have been inactive (where activity is determined on the basis of the brightness curve versus distance and on the existence of any low surface brightness coma) within 6 AU. In many cases pre-perihelion, activity has not begun until between 2-3 AU for the periodic comets. In the case of P/Halley, activity began near 6 AU, which is the farthest distance at which the equilibrium sublimation temperatures are warm enough for the initiation of water ice sublimation. Post-perihelion, however, P/Halley was still bright with an extensive coma at 10.7 AU. The extended period of activity may have been due to a thermal lag in the heat penetration into the interior. Observations at 12.2 AU with the Canada-France-Hawaii Telescope placed an upper limit to the brightness of P/Halley of 24th mag, which indicated that by this time the activity had ceased. The dynamically new comets, on the otherhand, *all* appear to be active at large distances. Some, for example, even have tails in excess of a million km near 10 AU. The figure below illustrates the dramatic difference between the brightness and activity for the periodic comets (+, where P/Halley is plotted as filled circles pre-perihelion and open circles post-perihelion) and the dynamically new comets (x). Chiron is included in the figure (boxes) for comparison. Work on modelling the activity for sublimation of various ices is in progress.



Radar Images of Near-Earth Asteroid 1989 PB........S.J. Ostro

S. J. Ostro, Jet Propulsion Laboratory

J. F. Chandler and I. I. Shapiro, Center for Astrophysics

A. A. Hine, National Astronomy and Ionosphere Center

Radar observations of the Earth-approaching asteroid 1989 PB, carried out at the Arecibo Observatory just ten days after the asteroid's discovery by E. Helin at Palomar Observatory, provide the first two-dimensional images of a kilometer-sized planetary object. The images place 20 to 50 pixels on the asteroid, depending on the object's rotation phase. The longest imaging sequence contains 64 frames and runs for 2.5 hours. The frame-to-frame rotation of the asteroid is readily apparent and shows the object rotating through 180° in about two hours.

Asteroid 1989 PB has a bifurcated distribution of mass and resembles two half-mile-sized objects in contact, or nearly so. 1989 PB may have formed as a result of collisional disruption of a much larger object in the main asteroid belt, when two fragments that had been dispersed by that collision at low relative velocity became gravitationally bound to each other.

1989 PB is one of more than one hundred known Earth-approaching asteroids. This population probably includes about 1000 objects at least as large as 1989 PB. Most of these objects probably come from the main asteroid belt between Mars and Jupiter, but some might be extinct comet nuclei. Their orbits are unstable and they will last no more than a hundred million years before being ejected from the solar system or being destroyed in a collision with one of the inner planets. If double objects turn out to be abundant in the near-Earth population, it would help us to understand the existence, on the Moon and Earth, of numerous impact-crater pairs that apparently were created by nearly simultaneous impact of two widely separated projectiles.

CO and Oxygen Chemistry on Titan .... T. Owen

Titan offers us an evolving atmosphere that is still in a reducing condition; it is a wonderful natural laboratory for testing our ideas about the origin and evolution of planetary atmospheres. The Voyager 1 flyby in 1981 revealed that the atmosphere of Titan is predominantly composed of nitrogen and methane. A large number of minor constituents are also present, formed in the stratosphere by chemical reactions between fragments of these two major components. In addition, a trace of CO_2 was found, a very surprising discovery in such a reducing environment. We would like to know the source of this CO_2, as well as the origin of the major gases, nitrogen and methane.

Because the surface temperature is so low on Titan ($T_s \sim 84^o$ K) the CO_2 must be formed in the stratosphere rather than simply being in vapor equilibrium with solid CO_2 on the surface. There are two likely pathways for producing CO_2; both require the existence of CO in the atmosphere as a precursor.

1. $H_2O + h\nu \rightarrow H + OH$

   $CO + OH \rightarrow CO_2 + H$

2. $CO + e \rightarrow C + O\,(^1D) + e$

   $O\,(^1D) + CH_4 \rightarrow OH + CH_3$

   $CO + OH \rightarrow CO_2 + H$

The H_2O in process (1) was thought to come from meteoritic bombardment. The origin and even the existence of the CO were not proved.

The Voyager instruments were unsuitable for CO detection, but we were able to succeed here on Earth using the FTS at the 4-m Mayall telescope at KPNO in 1982. Barry Lutz, Catherine de Bergh and I detected the 3-0 band of CO at 1.6 μm in Titan's spectrum, deriving a mixing ratio of 6×10^{-5}. This detection still leaves several questions open, viz. what is the source of the CO? What is the process by which CO is converted to CO_2?

The answers to these questions may be linked. There are two possible origins for the CO: it may be primordial, a remnant from the formation of Titan, or it may be secondary, also produced by externally supplied water, this time through a reaction between OH and the methyl radical:

3. $CH_3 + OH \rightarrow CO + 2H_2$

Recent microwave observations (also from Earth) indicate a depletion of CO in Titan's stratosphere compared with the amount we measured in the satellite's lower atmosphere. If this difference is real, it suggests some destruction of CO in the stratosphere, which would argue against the production of CO from CH_3 and OH. This would imply that the CO is primordial. There is another reason for this suggestion, as we shall see in Highlight (2).

Regardless of how this turns out, the discovery of CO proves that a source of oxygen is indeed present in this cold, hydrogen-rich atmosphere. This means that the chemistry taking place on Titan is even more interesting for possible comparisons with conditions on the early Earth. The Cassini-Huygens mission, with a probe that will descend through Titan's atmosphere to reach the satellite's surface, is bound to make some fascinating discoveries when it arrives in 2002.

Deuterium in the Outer Solar System .... T. Owen

It has long been recognized that the study of isotopic abundances is a very important and useful tool in attempts to understand the origin and evolution of planetary atmospheres. In the outer solar system, where hydrogen is such an abundant constituent, determinations of the relative abundance of the heavy isotope of hydrogen commonly called deuterium (D) are particularly significant. We can do this by observing HD and H_2, CH_3D and CH_4, NH_2D and NH_3, etc.

The Voyager IRIS experiment was able to detect CH_3D at 8.6 μm on both Jupiter and Saturn, allowing determinations of D/H in the atmospheres of these two planets. This same feature is present in the spectrum of Titan, but it is blended with an emission from propane. Uranus and Neptune were too cold to permit Voyager studies at this wavelength.

Several years ago, my colleagues and I set out to determine the deuterium abundances in the outer solar system by studying an overtone of CH_3D, at 1.6 μm that we first observed and characterized in the laboratory. Using ground-based observations of the 1.6 μm region of Saturn, Titan, Uranus and Neptune, Catherine de Bergh, Barry Lutz, Jean Pierre Maillard and I were able to detect lines from the $3\nu_2$ band of CH_3D and determine D/H on all of these bodies. We could not include Jupiter because of interference by ammonia absorptions. The observations were made with the 4-m Mayall telescope on Kitt Peak and the 3.6m Canada-France-Hawaii Telescope on Mauna Kea. A Fourier Transform Spectrometer was used in each case.

We found that our derived value of D/H on Saturn agreed well with the Voyager results obtained using a different band and a different analytical technique. We therefore felt confident in applying the method to the other objects. Subsequent to our derivation of a value for D/H on Titan, a careful analysis of the Voyager observations led to a virtually identical determination, further strengthening our conclusions.

The results of this comprehensive investigation showed that there are two distinctly different families of D/H values in the outer solar system. On Jupiter and Saturn, the measured values are close to 2×10^{-5}, whereas on Uranus, Neptune, and Titan, they approach 1.6×10^{-4}, the value found in terrestrial oceans. This is also the middle of the uncertainty range for the determination of D/H in Halley's Comet.

We interpreted these results to indicate that there are two different reservoirs of deuterium in the outer solar system. The larger one is the deuterium that is mixed with hydrogen gas. This large reservoir is the one that is being sampled when one determines D/H in a molecule such as methane (CH_3D) in the atmospheres of Jupiter and Saturn, where there is so much more hydrogen than anything else.

The smaller reservoir consists of condensed species that have been isolated from the hydrogen gas until they accumulated into planets, satellites, comets or meteorites. It is this reservoir that makes its appearance in the methane observed on Uranus, Neptune, and Titan. This second reservoir may in fact be made up of several components, since different molecules may have different values of D/H, depending on their prior histories.

We believe both reservoirs were established in the Interstellar Medium as a result of ion-molecule reactions. The fact that the high D/H reservoir has survived the planet formation process indicates that some large fraction of interstellar grains that formed the outer reaches of the solar nebula were not heated during the collapse of the nascent cloud and the formation of the disk. If that is true, we may also expect the survival of other interstellar molecules and abundance ratios. The persistence of primordial CO on Titan could be an example of this (Highlight 1).

HDO on Mars and the Early Martian Climate............T. Owen

Mars is the only planet in the solar system besides our own that shows evidence for the existence of liquid water on its surface. What we would like to know is when this water was present there, for how long, what the local conditions were, and how much water was involved. To answer these questions, we need to know far more about the planet than we can learn from simple inspection of surface topography. Most of this information will have to come from missions to Mars that investigate the composition of surface and subsurface materials, but some constraints can be established by remote investigations of the atmosphere.

Water vapor in the Martian atmosphere is continually being broken apart by ultraviolet light, allowing the hydrogen to diffuse through the atmosphere and escape into space. The present escape rate has been measured by UV spectrometers on spacecraft to be equivalent to the destruction of a global layer of water some 2.5 meters thick over the lifetime of the solar system. Since the mass of deuterium, the heavy isotope, is twice the mass of ordinary hydrogen, it will escape less readily. One can therefore expect some enrichment of deuterium in the water left behind on Mars as a result of this escape process. Some of the oxygen is also escaping from the planet, so a similar enrichment of the heavy oxygen isotopes should occur as well.

The Viking mass spectrometers that sampled the Martian atmosphere directly were unable to address the hydrogen-deuterium issue, but they found no measurable (to $\pm$ 5 %) enrichment of the oxygen isotopes. We resolved to try to measure the deuterium to hydrogen ratio from Earth by studying HDO and H_2O .

Using the Canada-France-Hawaii Telescope with its Fourier Transform Spectrometer, Catherine de Bergh, Barry Lutz, Jean Pierre Maillard and I were able to successfully record some 20 Doppler shifted Martian HDO lines in the ν_1 band near 3.7 μm in January 1987. Comparing these with H_2O lines measured at 1.1 μm, we found $D/H = 6 \pm 3$ times the terrestrial value.

In other words, a large enrichment of deuterium has occurred on Mars, despite the normality of the oxygen isotopes. We think this demonstrates two things: that the escape of hydrogen must have been more rapid in the past, implying the existence of large amounts ($>$ 100 meters) of water exposed to the atmosphere, and the existence of a gaseous reservoir containing oxygen that could exchange with the oxygen in the water to maintain the terrestrial value of the oxygen isotopes. This reservoir most probably consisted of carbon dioxide. The required amount is equivalent to an atmosphere with a surface pressure $\geq$ 600 mb.

Since this CO_2 had to be available at the time the rapid escape was occurring, these results support models for an early, warm, dense atmosphere on Mars. In other words, it seems to us that the simplest way to achieve the enrichment of the deuterium and the normality of the oxygen is to have lots of water on the surface, and a relatively thick atmosphere. These conditions support each other since the high surface pressure stabilizes the water and the combined CO_2 and H_2O provide a greenhouse effect that maintains a warm surface temperature. Such conditions also favor a more rapid escape of hydrogen by getting more water vapor into the atmosphere.

But is this really what happened, or are there other ways to interpret these results? This is the subject of an ongoing debate at the present time, which has already led to a definition of key experiments to be performed on future missions to Mars.

Evidence for Magnetospheric Effects on the Sodium Atmosphere of Mercury................................A.E. Potter

A. E. Potter and T. H. Morgan

Monochromatic images of Mercury at the sodium D_2 emission line showed excess sodium emission in localized regions at high northern and southern latitudes, and day-to-day global variations in the distribution of sodium emission. These phenomena support the suggestion that magnetospheric effects could be the cause. Sputtering of surface minerals could produce sodium vapor in polar regions during magnetic substorms, when magnetospheric ions directly impact the surface. Another important process may be the transport of sodium ions along magnetic field lines towards polar regions, where they impact directly on the surface of Mercury, and are neutralized to regenerate neutral sodium atoms. Day-to-day variations in planetary sodium distributions could result from changing solar activity, which can change the magnetosphere in time scales of a few hours. Observations of the sodium exosphere may provide a tool for remote monitoring of the magnetosphere of Mercury.

Radar Studies in the Solar System.............................. I.I. Shapiro

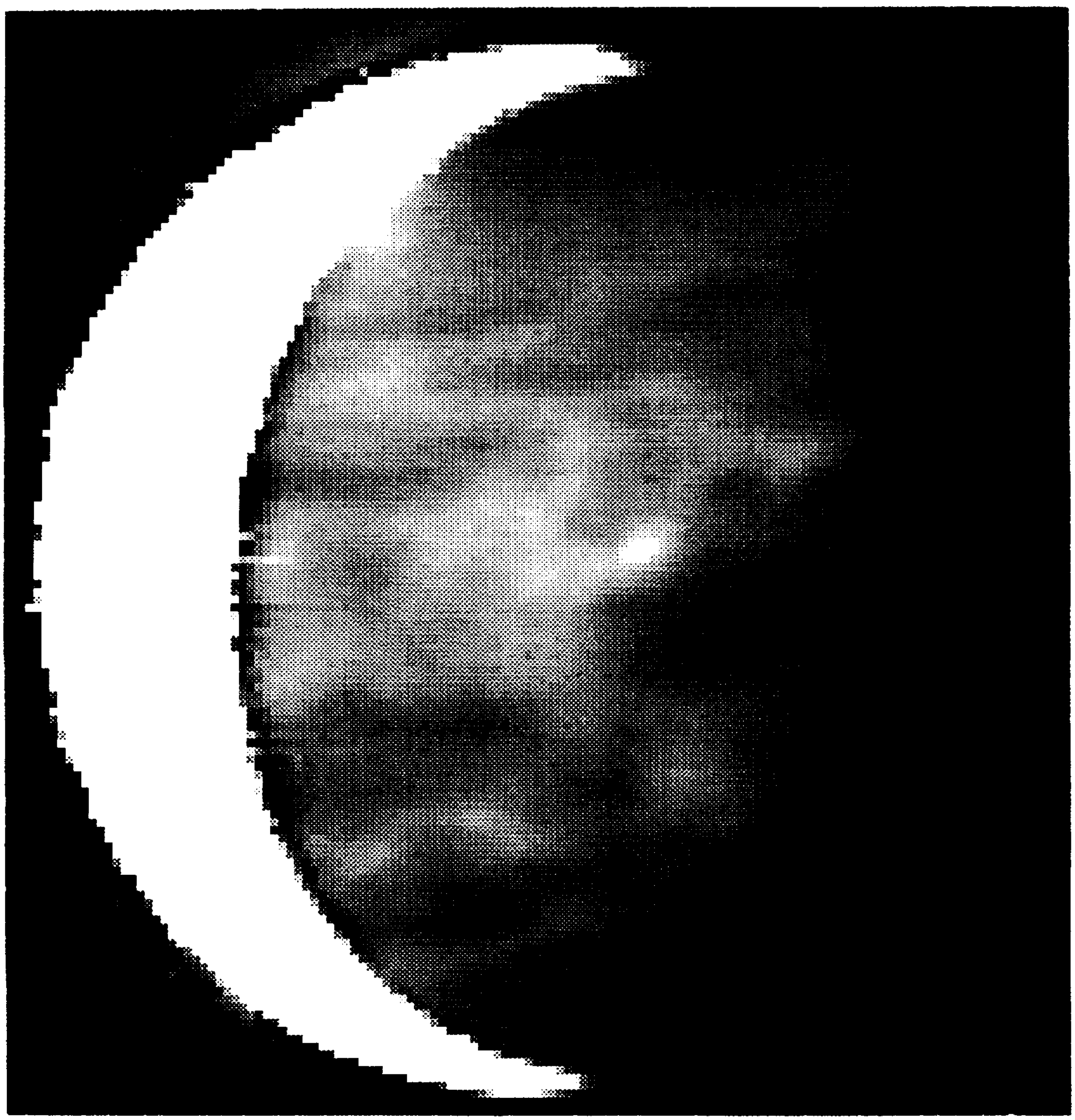
We have actively engaged in observations of asteroids and comets both as systematically planned targets and as "targets of opportunity." A striking example of the latter was asteroid 1989 PB, which was discovered optically on 1989 August 9 and found to be rapidly approaching the Earth. Our colleague S.J. Ostro had observing time available at Arecibo on August 19-22, when the asteroid would be within the Arecibo declination window, and we made daily ephemeris refinements based on the available optical data beforehand and on the preliminary radar data during the observing run. The result was a remarkable picture of an asteroid bifurcated into two distinct lobes and spinning with a period of about four hours.

The observing program also covered five other asteroids besides 1989 PB, plus the four Galilean satellites of Jupiter around the 1989-1990 opposition. We are gaining understanding of the surfaces of both rocky and icy bodies from analysis of these results.

Our analysis of radar observations of surface features on Venus has led to an improved knowledge of Venus' spin vector and a convincing demonstration that it is not in a spin-orbit resonance with Earth, despite the fact that Venus presents very nearly the same face to Earth at each inferior conjunction.

Near Infrared Imaging of Venus................................W. Sinton

Images of Venus at 2.3 micron show evidence for emission with fine spatial structure. Near IR array imaging was undertaken from Mauna Kea in conjunction with the Galileo flyby of Venus in February 1990. The attached image is from the 256 x 256 pixel NICMOS array, installed at the UH 2.24-m telescope. The image shows structure on scales as small as 1 arcsecond. Note the bright, point-like emission from the center of the night-side. The Mauna Kea NICMOS data are the highest quality ground based images of Venus yet obtained.

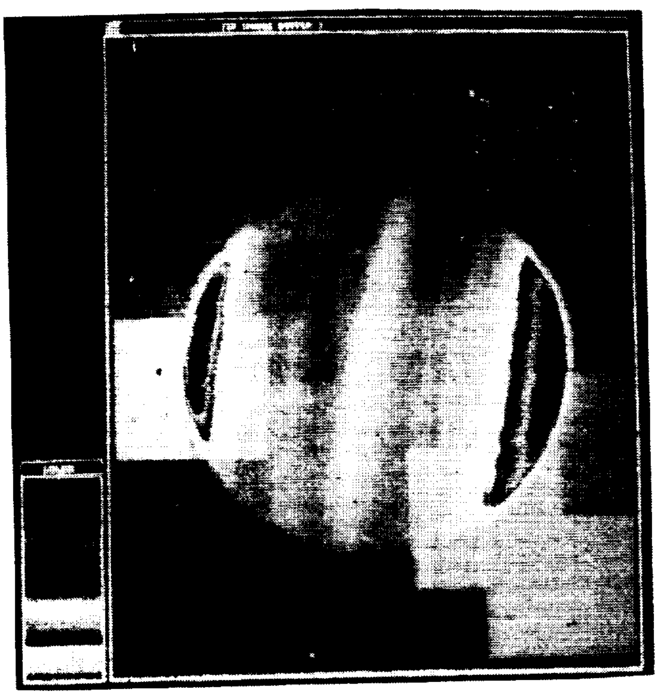


Observations of Formaldehyde in Comet Machholz (1988j) .... L.E. Snyder

The VLA was used in September, 1988, to detect the 1_{11} - 1_{10} transition of formaldehyde (H_2CO) in emission at 6 cm wavelength (4829.659 MHz rest frequency) from Comet Machholz, a new comet (Snyder, Palmer, and de Pater 1990, Icarus, in press). The cometary line had a small blueshift of -0.76 ± 0.40 km s^{-1}, which is consistent with the anisotropic outgassing of the nucleus in the solar direction and very similar to the blueshift observed in January, 1986, with the VLA for the H_2CO emission line from Comet Halley (Snyder, Palmer, and de Pater 1989, Astron. J. **97**, 246). The derived H_2CO production rate for Comet Halley was 1.5×10^{28} mol s^{-1}, and for Comet Machholz it was about an order of magnitude larger, 2×10^{29} mol s^{-1}. Comet Machholz faded considerably only days after these H_2CO observations, which suggests that it fell apart. Indeed, the Comet Machholz H_2CO line is ≈ 2.5 times wider than the Comet Halley H_2CO line, which may indicate that the comet had started to come apart during these VLA observations.

Research in Planetary Astronomy at Palomar Observatory .... B.T. Soifer

The introduction of infrared arrays has revolutionized the study of the planets and solar system bodies. We have utilized the near infrared Cassegrain camera on the 200-inch Hale telescope to study several planetary systems in the infrared. The accompanying pictures, obtained with this camera, show Jupiter 2.3μm, and Uranus at 2.2μm. In the image of Jupiter, the blue is faint and red is bright. This image shows the effect of the very strong methane absorptions. The bright caps show the limb brightening effect associated with scattering of aerosols high in the atmosphere, as compared to the strong methane absorption at lower latitudes. The image of Uranus at 2.2μm shows the drastic change in relative brightness of the planetary disk compared to the ring. In the visible, the ring is invisible because of the very bright planet, while at 2.2μm, the planet is much fainter because of the strong atmospheric absorption of methane, and so the ring is easily visible. These images demonstrate the power of probing planetary systems with infrared images.



The image on the left is a mosaic of false color images of Jupiter taken at 2.3μm, in the depth of the strong methane absorption band. Red is bright and blue is faint. The bright polar caps are believed to be a result of light scattering by aerosols in the stratosphere of Jupiter. The image on the right is of the Uranus system at 2.2μm. The ring system, invisible in optical images, is clearly visible, and is brighter than the disk of the planet.

A Three-Parameter Asteroid Taxonomy System....... E.F. Tedesco

The three-parameter asteroid taxonomy system is a convenient, pragmatic scheme which will be useful for classifying large numbers of asteroids observed in surveys. The rational for this three-parameter taxonomy lies in the fact that the most readily-measured, physically-meaningful parameters for an asteroid are its spectrum and its albedo. Asteroid spectra show, at most, strong absorption features in two regions of the spectrum between 0.3 and 1.1 μm. The U-V color index (0.36 to 0.55 μm) is a measure of the strength of the short wavelength absorption feature while the v-x (0.55 to 0.85 μm) color index provides a measure of the strength of the long wavelength feature.

The three-parameter method begins by generating a six-sided error-box for each asteroid formed by the three parameters and their uncertainties. Each of the previously defined volumes in the three-dimensional parameter space are searched in turn. If the error-box, in its entirety, is found to be included in one of them then it is assigned as a member of that class. If part of the error-box lies outside the class volume, but not within the class volume of another class, then a question mark is appended to the single-letter class. If the error-box intersects two class volumes then a two-letter class is assigned. When an error-box intersects three or more class volumes all class labels are concatenated. In practice, only one of the 357 asteroids in the high-quality classification data set generated a three-letter class and none were assigned four or more letters. Finally, if the error-box is found to lie wholly outside of all class volumes then it is considered to be unclassifiable in this system. Fourteen such asteroids were found.

11 classes are recognized in the three-parameter system. This result is based on the 303 asteroids (85% of the defining sample) with single-letter, i.e., "certain", classifications. Most of the asteroids in the sample have albedos which fall on either side of values between 0.072 and 0.141, inclusive. This is the well-known gap in the bimodal asteroid albedo distribution. Four classes (A, D, E, and P) have albedos which fall well outside of this gap.) Of the remaining classes the C, F, and S classes have 5%, 11%, and 14% of their members, respectively, with albedos in this gap. 62% of the M class and 83% of the G class are found in the gap while this is true for 100% of the K and T classes.

The classes with all of their members in the gap contain no large asteroids, i.e., none of the K or T class members has a diameter exceeding 110 km. We are currently investigating the reason for this. One possibility is that the smaller asteroids are predominately the cores of larger parent asteroids which were collisionally disrupted. It would then not be unreasonable to expect that such asteroids would have different surface mineralogies from the larger, essentially intact, asteroids.

Further research into this question is continuing.

A Newly Discovered Species on Io .... L. Trafton

On January 29, 1989 (UT), L. Trafton and D. F. Lester discovered a new absorption feature in Io's near-infrared spectrum which is not present in the spectra of Jupiter or the other Galilean satellites. This 2.125 μm feature is the only absorption feature known in the K-band (1.9 - 2.6 μm). Although absorption features have been recently discovered beyond 3 μm due to H_2S, this feature does not lie at a H_2S wavelength. Unlike the absorption features at longer wavelengths, this feature is very narrow, with FWHM < 25 Å. It is very unlikely that such a narrow feature can arise from a pure solid material. This exciting result suggests the presence of another gaseous component to Io's atmosphere or else a gas locked in a clathrate. If gaseous, it would have important implications for the composition and bulk of Io's atmosphere. The feature so far does not show any significant temporal variation or correlation with Io's volcanos. Laboratory experiments are underway at NASA/AMES to identify the feature.

Jupiter's Near-Infrared Aurorae .... L. Trafton

New observations of Jupiter's near-IR (K-band) aurorae, first detected by L. Trafton and colleagues, confirm the strength, longevity, and time variability of these emissions. One of Trafton's unidentified sets of Jovian emission lines has been identified as H_3^+ by J. K. G. Watson at the Herzberg Institute for Astrophysics. This identification was made using Jovian spectra later obtained at the CFHT telescope by Drossart and colleagues, who had independently discovered these lines. These represent the first remote detections of this species in an astrophysical source. Other sets of lines exhibiting different spatial and temporal behaviors from the identified lines remain to be identified. Trafton and colleagues reported the H_2 and H_3^+ lines to be emitting in December after they were reported absent by Oka and Geballe in September, who had observed from the UKIRT. However, the intensity was less than last winter's values. Preliminary estimates of the rotational temperature of H_2 from the Q-branch lines near 2.4 μm imply a drop from ~ 1750 K on December 31, 1988 to 1250 - 1450 K on January 29, 1989. The H_2 emission appears to be confined mostly to high latitudes (north and south) but some equatorial emission appears to be present, even at longitudes relatively shielded from the trapped radiation belts. The H_3^+ emission also appears to be confined to high latitudes and is about equally strong in the northern and southern aurorae. It is associated with the H_2 emission regions but does not track the H_2 emission strength. The brightest northern emission observed so far has been at System III (1965) longitude 125 deg, but bright emission is also observed at 180-200 deg.

Other emission lines, so far unidentified, are observed to extend to lower latitudes, especially for the southern aurora which has exhibited great extent in these lines. On Nov 24, 1988 southern auroral emission at 2.1055 μm was observed to extend to within 25 deg of Jupiter's equator at a longitude of 7 deg. In addition, the southern aurora extended at least from 290 deg to 7 deg. Unidentified emissions at 2.219 μm, 2.237 μm and 2.246 μm were also seen in this aurora. Some emission lines have been detected only in one of these hemispheres. Equatorial emission is also seen at 2.110 μm against the dark pressure-induced H_2 background, especially at the east and west limbs. An emission feature at 2.224 μm has been observed at the center of the disk. This exists in a strong CH_4 band. Further observations are underway to better delineate the spatial and temporal behavior of Jupiter's 2 μm aurorae, to establish the excitation regimes, and to provide information helpful for identifying the unknown species.

Pluto's Post-Perihelion Behavior .... L. Trafton

The post-perihelion and seasonal dependence of Pluto's atmosphere and surface ice composition may be quite complex if two or more volatile gases make up the atmosphere. L. Trafton found that over a range of parameters for a CH_4-N_2 atmosphere, Pluto's atmosphere would hardly freeze out at aphelion (unlike the case for a single-component volatile atmosphere). Other findings were that bulk atmospheric escape occurs for CH_4 mole fractions of Pluto's volatile reservoir less than 0.07 if N_2 is the second gas. Greater CH_4 abundance leads to diffusive separation during the escape of both species with an upper limit to the CH_4 mixing ratio close to 0.07. Observing the anticipated post-perihelion and seasonal changes in Pluto's spectrum is expected to provide important information on the composition of Pluto's primordial volatile reservoir, which annually replaces the escaping atmosphere.

The composition of the surface of the volatile deposit or exposed reservoir is generally different from the rest of the solid because it is controlled by the atmosphere. Because N_2 and other candidate volatile gases for Pluto's atmosphere have saturation vapor pressures several orders of magnitude higher than for CH_4, the CH_4 composition of the surface volatile deposit is greatly enhanced over that of Pluto's volatile reservoir. Since the surface contributes strongly to the observed CH_4 spectrum, estimates of Pluto's bulk CH_4 composition may be grossly overestimated. This would bring Pluto's internal CH_4 composition closer to cosmochemical expectations based on an origin in the outer solar nebula.

J. G. Williams and J. Gibson

Jet Propulsion Laboratory, California Institute of Technology

Comets and planet crossing asteroids are observed so that accurate positions may be determined. The observations are made with the Palomar 1.5m telescope equipped with a CCD array. This combination of telescope and detector is quite efficient at recording faint comets and minor planets. This proves quite useful for early acquisition of comets and asteroids returning for a new opposition. These recoveries of comets and planet crossing asteroids during the past year are discussed below.

Of nearly two dozen comets observed during the past year, eight were recoveries of periodic comets. One recovery, P/Schwassmann-Wachmmann 3, was shared with another observatory. The total number of comets recovered under this program now stands at 40. The eight recovered comets are listed in the table below.

Comet Name	Designation
P/Du Toit-Neujmin-Delporte	1989l
P/Gehrels 2	1989n
P/Wild 2	1989t
P/Kearns-Kwee	1989u
P/Tuttle-Giacobini-Kresak	1989b1
P/Schwassmann-Wachmann 3	1989d1
P/Russell 4	1989g1
P/Van Biesbroeck	1989h1

More than two dozen planet crossing asteroids were observed during the year. Included were second-opposition recoveries of three asteroids which can pass near the earth. They are 1987 QA (subsequently numbered 4257), 1987 UA, and 1989 FB. They are an Apollo, an Amor, and an Apollo, respectively.

Cometary Dynamics and Nucleus Characteristics..... D.K. Yeomans

Using the recently developed nongravitational acceleration model for active comets, the radial nongravitational acceleration acting upon a comet's nucleus can be determined at any point on its orbit. The mass of the comet multiplied by this nongravitational, radial acceleration is then equal to the mass loss per unit time times the velocity of the escaping gases. The mass loss per unit time can be estimated from the water production rates that are deduced from the photometry of hydrogen and the hydroxyl radicals and the velocity of the escaping gases is known to a few percent. Thus, the mass of the nucleus can be estimated. For comet Halley, the mass has minimum and maximum values of 1.3×10^{17} and 7.8×10^{17} grams with a nominal value of approximately 5.0×10^{17} grams. Depending upon which of several published volume estimates for Halley's nucleus is used, the nucleus bulk density has minimum and maximum values of 0.3 and 2.1 g/cc with a nominal value of 1.2 g/cc.

A similar type of analysis for comet Brorsen-Metcalf suggests that the record early arrival of this comet to perihelion (nearly 16 days ahead of its predicted perihelion passage!), can be explained if this comet's effective radius is approximately 5 times smaller than Halley's radius.

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